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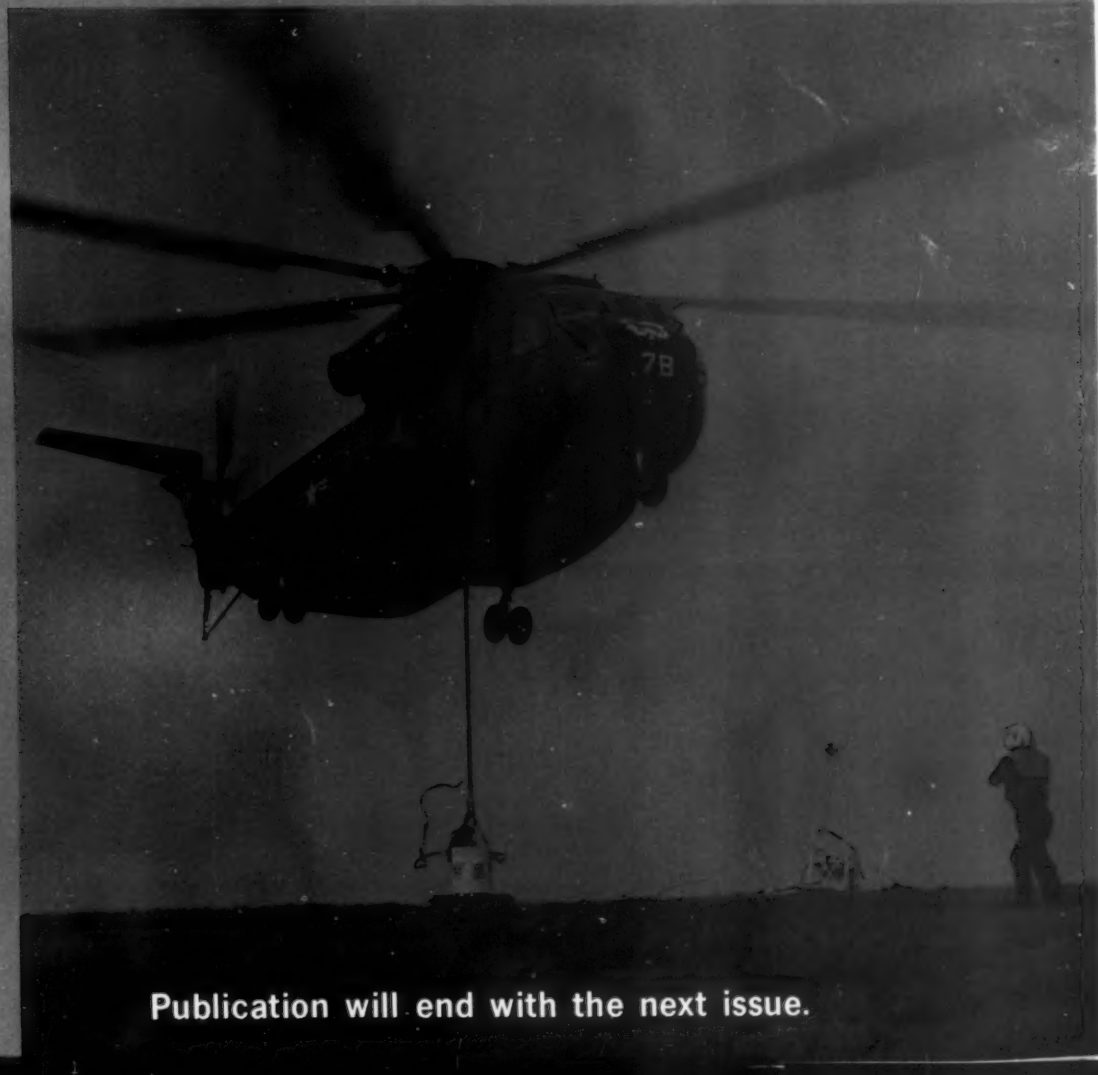

Publication will end with the next issue.

TECHNICAL PROGRESS REVIEWS

The United States Atomic Energy Commission publishes the Technical Progress Reviews to meet the needs of industry and government for concise summaries of current nuclear developments. Each journal digests and evaluates the latest findings in a specific area of nuclear technology and science. *Nuclear Safety* is a bimonthly journal; *Reactor Technology* is a quarterly journal.

Nuclear Safety
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Nuclear Safety Information Center, Oak Ridge National Laboratory

Reactor Technology
Prepared in cooperation with the American Nuclear Society

Both are available from the U. S. Government Printing Office. See the back cover for ordering instructions.

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Availability of Reports Cited in This Review

United States Atomic Energy Commission (USAEC) reports are available at the libraries listed on the inside front cover of each issue of *Nuclear Science Abstracts*. USAEC reports are also sold by the following governmental and international organizations: (1) National Technical Information Service (NTIS), U. S. Department of Commerce, Springfield, Va. 22151; (2) International Atomic Energy Agency (IAEA), Vienna, Austria; and (3) National Lending Library, Boston Spa, England.

Other U. S. Government agency reports identified in this journal are generally available from NTIS.

Reports from other countries are generally available at the same U. S. libraries as maintain collections of USAEC reports, and from IAEA and the originating country. **United Kingdom Atomic Energy Authority (UKAEA)** reports are sold by Her Majesty's Stationery Office, London. **Atomic Energy of Canada Limited (AECL)** reports are sold by the Scientific Document Distribution Office, Atomic Energy of Canada Limited, Chalk River, Ontario, Canada. UKAEA and AECL reports issued after March 1, 1967, are sold by NTIS to purchasers in the United States and its territories. IAEA publications are sold in the United States by UNIPUB, P. O. Box 433, New York, N. Y. 10016.

Private-organization reports should be requested from the originator.

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COVER: Placement of a radioisotopic power generator near a weather-station installation on San Miguel Island. Official U. S. Navy photo.

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Isotopes and Radiation Technology

is a Technical Progress Review prepared by the Isotopes Information Center, Oak Ridge National Laboratory, at the request of the Office of Information Services and the Division of Applied Technology, U. S. Atomic Energy Commission. This Review is intended to assist those interested in keeping abreast of significant developments in the fields of isotopes and radiation technology. It is not a comprehensive review of all literature published in this field during a given quarter; rather, it is a mechanism for presenting concise, selected reviews of information on subjects of prevailing Commission interest as it becomes available.

This Review attempts to relate the published results of research and development sponsored by the Division of Applied Technology to significant developments in radioisotopes and radiation technology, as reported in the world literature. Coverage includes isotope production and development, isotope technology development, isotope applications technology, process radiation development, and radiation processing of food and medical supplies.

In addition to reviews of current literature and special review articles dealing with specific isotopes, facilities, and applications, this publication occasionally contains feature articles prepared by recognized experts on specific topics of current interest. Critical evaluations and interpretations presented are those of the editors and invited reviewers; therefore readers are encouraged to consult the original references in order to obtain all the background of the work reported and the interpretation of the results given by the original authors.

Insofar as feasible all references are checked by the editors, using the library facilities of Oak Ridge National Laboratory, Oak Ridge Associated Universities, and the University of Tennessee. Occasionally, however, the cited material is not available; such cases are identified by an asterisk (*).

The subject headings listed below have been adopted to help maintain continuity and order, from one issue to the next, in the material reviewed. All reviews, except Feature Articles, will be arranged under these headings; but any one issue will not necessarily contain all the headings.

Isotope Production and Development
Isotope Technology Development
Food Irradiation
Process Radiation Development
Source Development
Isotopic Heat and Power Development
Applications in Life Sciences
Safety
Isotopes Around the World
Miscellaneous

P. S. Baker, R. H. Lafferty, Jr., Martha Gerrard, R. E. Greene, F. E. McKinney, and Helen P. Raaen, *Editors*
A. F. Rupp, *Adviser*

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PUBLICATION WILL CEASE

We are sorry to have to report that the next issue of *Isotopes and Radiation Technology* [i.e., 9(4)] will be the final one. Funds are no longer available for this particular effort; hence there is no way to continue.

We feel that, during the 9 years of its existence, this Technical Progress Review has served a very useful purpose; we appreciate the many kind comments of the readers to this effect. It is with sincere regret that we find it necessary to cease publication.

—*The Editors*

Recent Advances in Applications of Isotopes and Radiation in the United States*

By E. E. Fowler†

Supplementary Keywords: *DID open literature; production, radioisotope; medicine; tracer; diagnosis; absorptiometry; X-ray fluorescence; energy source; prosthetic device; heart; activation analysis; pollution; water and waste treatment; process radiation; enriched stable isotope use;* ^{14}C; ^{99m}Tc. ^{153}Gd; ^{152}Eu; ^{238}Pu; ^{147}Pm; ^{16}O.

Abstract: *This paper presents an overview of recent developments in radioisotope and radiation technology in the United States with emphasis on areas that can best benefit developing nations. Growth in the quantity and variety of radioisotopes produced in the United States is discussed in relation to use trends. New radioisotopes now being developed for large-scale use in the United States are identified and their potential applications are described, with emphasis on medical uses. The successful production of "medical grade"* ^{238}Pu *oxide is described in a status report of the U. S. Atomic Energy Commission (USAEC) Artificial Heart Program.*

Field experience with newly available radioisotope instruments and tracer techniques, which have special utility in developing nations, is critically examined. These include radioisotope X-ray-fluorescence analyzers for industrial uses, two new types of radioisotope snow gages, a sediment-tracing system for coastal waterways studies, an oil-slick-identification technique, new gages for highway construction, and new gaging and on-line analysis techniques for control of mineral beneficiation. Special attention is given to work under way on the use of radioisotopes and radiation in air- and water-pollution measurement and control.

The current usage of both accelerators and radioisotopes as radiation sources in processing industrial products in the United States is discussed. The USAEC programs on Radiation Processing and Food Irradiation are described. The properties of several potentially useful new composite materials produced by radiation processing are given. The paper concludes with a discussion of the policy considerations that guide the USAEC Isotopes Development Program.

Almost exactly a quarter of a century ago, the first shipment of a reactor-produced radioisotope was made in the United States. In August 1946, the Clinton Laboratories [now Oak Ridge National Laboratory (ORNL)] made available the first millicurie of ^{14}C for cancer research. Papers to be presented at this Conference provide ample evidence of the humanitarian benefits which radioisotopes have brought to the world since that time.

RADIOISOTOPES PRODUCTION FOR MEDICAL APPLICATIONS

From no other aspect of atomic energy application does the general public in the United States benefit more directly and extensively than from the use of radioisotopes and radiation in medical research, diagnosis, and therapy. To place a dimension on the extent of use, over 4 million persons were diagnosed or treated using radioisotopes in 1970. This compares with 2 million diagnoses or treatments in 1965, the year of the last Geneva Conference.

The development and continuing improvement of radioisotope scanning systems have been a very important factor in the clinical acceptance of this technology. In addition, the remarkable sensitivity of the

*Paper presented at the Fourth International Conference on the Peaceful Uses of Atomic Energy, Geneva, Sept. 6–16, 1971.

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multidetector Anger camera system has extended diagnostic procedures substantially by showing rapid changes in radioisotope uptake patterns. A new kind of tomographic scanner[1] has now been developed at the Lawrence Berkeley Laboratory for simultaneous recording of radioactivity emitted by isotopes lying at different levels in the body. Lesions at unknown depths can be found more easily than with presently available single-focal-plane scanners.

Details of new diagnostic applications of radioisotopes in the United States are covered by Wagner, Taplin, and Rupp[2] in another session of this Conference. Recent clinical investigations using ^{67}Ga and ^{18}F for diagnosing suspected malignancies and metabolic disorders are especially encouraging.

Whereas most new instrumentation developments are usually commercially available to developed and developing nations alike, the trend in medical radioisotope production research has been toward shorter-lived nuclides and unique production devices, both of which limit their availability. For example, a new family of spallation-produced radioisotopes will soon be available for evaluation from a recently initiated USAEC production-evaluation program, which will utilize the excess (about 70%) 200-MeV proton beam of the linear accelerator injector for the Brookhaven Alternating Gradient Synchrotron. Products to be investigated in this unique facility will include ^{88}Y, ^{67}Cu, ^{28}Mg, and ^{52}Fe with half-lives of 107 days, 78 hr, 21 hr, and 8 hr, respectively.

More pertinent to developing-nation needs, perhaps, are recent developments in the diagnostic applications which are already in wide-scale use today. For example, Brookhaven National Laboratory (BNL) has made some significant developments that extend the utility of ^{99m}Tc, which is already in widespread use for diagnosis of liver, brain, and kidney diseases. Recent studies by Atkins, Hauser, and Richards[3,4] on several hundred patients indicate that ^{99m}Tc as pertechnetate, the form in which it is eluted from ^{99}Mo–^{99m}Tc generators, is also useful for thyroid-function and -visualization studies.

Eckelman and Richards[5] working with the same Brookhaven team have been quite successful, to date, in simplifying the radiopharmaceutical preparation procedures for other common applications. Their goal is to develop a series of "instant reagents" that mix with the radioisotope to form the desired pharmaceutical product in a single step. So far, they have perfected two such reagents using ^{99m}Tc—diethylenetriamine pentaacetic acid for liver scanning and human serum albumin for blood pool studies.

Richards[6] has also developed simple extraction techniques that permit use of the low-specific-activity ^{99}Mo, which is available from low-flux reactors. Work by Belkas and Perricos[7] in Greece has demonstrated the practical utility of this latter development for medical isotopes production in developing nations.

All these new procedures, however, presuppose the routine availability of ^{99}Mo–^{99m}Tc generators; this is not the case in many developing countries. A new nuclear technique under development by Hoffer[8] holds promise for diagnostic measurement even where no radiopharmaceuticals are available. In this technique the natural iodine in the thyroid gland is measured by X-ray fluorescence. This technique has now been successfully used on over 300 patients at the Argonne Cancer Hospital for all common thyroid diagnoses that usually employ ^{131}I. The 60-keV gamma rays from an ^{241}Am source, mounted externally on the scanning device, penetrate into the thyroid gland where they excite the characteristic iodine X rays. These secondary X rays are then selectively detected in a Si(Li) detector to obtain the usual visual "image." The technique exposes the patient to a very low radiation dose (15 mrads) in the immediate vicinity of the thyroid only. Work is now under way by Patton, Brill, and Johnston[9] at Vanderbilt University to evaluate the technique for monitoring stable-bismuth uptake in tumors, using ^{153}Gd for excitation.

The USAEC is now producing or developing several new fission and neutron products for large-scale use in a variety of applications, including potentially valuable medical applications. For example, the anticipated therapeutic advantage of ^{252}Cf neutrons over gamma and X rays for tumor control was one of the reasons for the USAEC's undertaking the large-scale production and market-development program for this isotope. The current status of use of ^{252}Cf for this purpose is discussed by Suit[10] elsewhere at this Conference.

The 242-day ^{153}Gd, a low-energy gamma-emitting isotope now under large-scale development, is another isotope which has potential for medical application. This radioisotope has been used in small quantities for many years, but its cost has been prohibitive because of the low natural abundance of ^{152}Gd—the target material needed to produce it in a reactor. Its "new" availability derives from the large quantities of ^{152}Eu that are produced in the europium control rods used in the Oak Ridge High Flux Isotope Reactor (HFIR). The ^{152}Eu converts to ^{152}Gd by beta decay. A single irradiated control rod contains about 80 g of ^{152}Eu. Work is under way now at ORNL to resolve the

technical and economic feasibility of the new production technology.

Cameron,[11] at the University of Wisconsin, has already used ^{153}Gd for measuring calcium in bones, by the gamma absorption technique. Its dual photon emission in the 100- and 50-keV regions makes it better suited for this use than the commercially available ^{125}I or ^{241}Am units. Perhaps more important to developing nations is the new potential that this radioisotope offers for taking conventional medical X rays, even chest X rays, in areas where electric power is not available and portability is needed. Sources of up to 5 Ci are presently being evaluated in several medical centers.

Large-scale production of ^{238}Pu has also provided unique opportunities in medical applications. Medical researchers have been quick to recognize that this isotope might be useful for powering heart pacemakers and even implantable artificial heart devices.

HEART PACEMAKER DEVELOPMENT

Most of the heart pacemakers being developed in the United States will be fueled with ^{238}Pu (Refs. 12, 13). However, at least two of the private pacemaker-development programs[14,15] are investigating the use of the fission-product radioisotope ^{147}Pm. One of these groups[15] is developing a unique implantation technique so as to be able to replace the relatively short-lived ^{147}Pm device (2.6 years half-life) by implanting and replacing the miniature device within the heart through an artery in the neck with only minor surgery. The technique has been successfully tested in animals.

The vigorous national and international pacemaker-development competition now under way indicates the importance of this application and of its potential for wide-scale use. The technology is progressing so rapidly that a current status report here is impractical.

ARTIFICIAL-HEART DEVELOPMENT

The deaths of nearly three-quarters of a million Americans each year from heart disease are a matter of national concern which has been given a high priority in the government's research and development efforts.

The community of heart surgeons performing heart transplants and those developing and using artificial heart devices uniformly comes back to one prime need—a reliable long-term power supply to meet the heart pumping functions.

One of the very few known possibilities for furnishing power to a completely implantable artificial heart is the use of nuclear energy from the man-made radioisotope ^{238}Pu. In view of the urgency of the requirements, the USAEC has been actively exploring ways in which this isotope might be used to power an artificial heart pump.

The problems associated with the development of a fully implantable radioisotope system for this application are much more formidable than those in the pacemaker development—largely because of the much bigger power source required for the blood pump (60 to 100 g of ^{238}Pu against about 150 to 500 mg for pacemakers). This requirement gives rise to a whole series of unsolved problems on the frontiers of biomedical engineering. The USAEC began to explore these problems in 1967 when, in cooperation with the National Heart and Lung Institute, four parallel study contracts were initiated to identify and evaluate key problems requiring solution. These studies identified a number of areas requiring extensive research and development, but all concluded that such efforts had a reasonable chance of success.[16]

From the start, the successful utilization of ^{238}Pu as a radioisotope heat source for heart devices obviously depended on demonstrating that an economical fuel could be produced reliably and in a pure form having minimal external radiation. To meet the very high chemical-purity requirements, Los Alamos Scientific Laboratory developed procedures for electrorefining ^{238}Pu to remove light-element impurities that give rise to enhanced neutron emission.

The composition of the ^{238}Pu fuel depends mainly on the required operating temperature of the heart device and on the temperature restraints imposed for reasons of safety. For relatively low temperatures, ^{238}Pu metal stabilized with a suitable material such as gallium would be satisfactory. However, for devices that require fuel temperatures of over 600°C, PuO_2 will be required. The oxide must be largely ^{16}O since the other isotopes of oxygen react with alpha particles from the ^{238}Pu, producing additional neutrons.

Table 1 compares the properties of plutonium oxide enriched in ^{16}O and metal produced from electrorefined ^{238}Pu. As can be seen from Table 1, an oxide fuel can be made that is comparable to the metal in radiation properties. (The metal neutron emission is approaching the irreducible minimum from spontaneous fission.) After consideration of all requirements, plutonium oxide enriched in ^{16}O has been chosen as the fuel form for high-temperature application in the artificial-heart program. Table 2 demonstrates the re-

Table 1 Comparison of the Properties of 30-W(t) Metal and Oxide Sources*

	^{238}Pu–3 at. % Ga	$^{238}Pu^{16}O_2$
Power, W	30.3	30.1
Fuel power density, W(t)/cm^3	7.18	4.07
Dimensions of Pu cylinder		
Diameter, in.	0.72	0.85
Height, in.	0.63	0.80
Neutron emission rate, n/(sec)(g Pu)	2535	2750
Dose rates at 10 cm		
Neutron, mrem/(hr)(g Pu)	0.25†	0.28‡
Gamma, mR/(hr)(g Pu)	0.16†	0.16†

*80 at.% ^{238}Pu, 1 ppM ^{236}Pu.

†Dose rate in air through 0.030 in. of Ta.

‡Dose rate in air through 0.068 in. of Ta–10% W and 0.025 in. of Hastelloy C-276.

Table 2 Neutron Emission Rates [n/(sec)(g)] of Electrorefined Metal, $^{238}Pu^{16}O_2$ Powder, and 1W(t) $^{238}Pu^{16}O_2$ Cylinders*

Electrorefined metal	$^{238}Pu^{16}O_2$ powder	1-W $^{238}Pu^{16}O_2$ cylinders
2460	2630	2695
2480	2670	2680
2425	2620	2655

*80 at.% ^{238}Pu.

producible nature of the electrorefining and ^{16}O enriching processes. Whether using a metal fuel or a pressed and sintered oxide, one can proceed with confidence that fuel meeting rigid radiation-output specifications can be produced.

The following additional investigations have been undertaken in this program:

1. Heat sources have been implanted in dogs to study problems that may arise from heat rejection.

2. The radiation dose has been determined and studied using phantoms and animal implants.

3. Medical-grade fuel has been developed to alleviate the radiation problem as previously discussed.

4. The National Heart and Lung Institute has supported a series of development projects on thermally powered heart engines which have provided new insight into the various subsystem requirements.

5. In April 1971 the USAEC initiated a 24-month program to develop information leading to a decision on whether a full-scale effort to develop a radioisotopically powered heart device for clinical use should subsequently be initiated. Two 7-month contracts were awarded for the first phase of a study to evaluate the practicality of a radioisotope thermal converter for a heart device. A subsequent phase will be performed by one of the two Phase I contractors. In addition, a third contract was awarded to develop a precursor radioisotope heat source for use in the converter.

INDUSTRIAL NUCLEAR MEASUREMENT SYSTEMS

The 1970 sales of radioisotope gages in the United States were $40 million.[17] Considering that the average payoff time for these systems from material savings alone is only about 6 months, the nation's economy has surely benefited substantially from this radioisotope application. More important, of course, is the safety and quality assurance that these instruments add to products used by the public. Following are some recent development trends in the United States in this area, which should prove useful to developing nations:

1. On-line nuclear thickness[18] and density gages are now being integrated into complete process-control systems along with several other sensing techniques. Sensor signals from several points in the process are fed into a central computer, which controls the process as a whole.

2. The use of nuclear techniques in the highway industry has grown rapidly. Over a thousand portable soil moisture–density gages are now in use in all 50 state highway departments in the United States. Gamma density devices are used for controlling the compaction of subgrade soil, and neutron-absorption devices for measuring the moisture in concrete and the content of asphalt.[19]

*3. Both portable and on-line[20] radioisotope X-ray-fluorescence (XRF) analysis systems, now available commercially in the United States, are finding a wide variety of applications, especially in mining and mineral beneficiation.

*4. The first commercial on-line neutron activation analysis (NAA) system in the United States[21] has proved very successful for measuring and controlling silica in the iron ore (taconite) beneficiation process. The third unit was recently installed, and additional mineral applications are expected soon. Investigations

*Although the XRF and NAA applications cited in items 3 and 4 above are industrial developments, much of the technology is available in reports of earlier USAEC development projects.[22,23]

now under way indicate that the use of ^{252}Cf neutron sources may soon expand this technology to several additional minerals.[24]

NEW RADIATION-DETECTOR DEVELOPMENT

The development of new and improved radiation detectors and detector systems has been a constant pursuit of the USAEC from its inception. Experience has proved repeatedly that any significant improvement in detector technology can open whole new areas of radioisotope applications. For example, many of the XRF and capture-gamma spectrometry applications cited in this paper resulted from development of Ge(Li) and Si(Li) detectors.

Several more recent developments in this area also look very promising. For example, the General Electric Company has recently made two new types of detectors commercially available, viz., (1) high-purity-germanium detectors[25] that require cooling only when in use and (2) contoured silicon detectors[26] that operate in an avalanche mode similar to Geiger tubes but have recovery times in the nanosecond range.

USAEC development programs with Hughes Research[27] and Tyco Laboratories[28] are making steady progress toward high-resolution detectors of CdTe, which give good energy resolution at room temperature. Mayer[29] recently reported that the Hughes group has developed such a detector with an energy resolution of 14-keV (full-width half-maximum) for 122-keV ^{57}Co photons with a peak-to-valley ratio of 25 to 1. When commercially available, these sensors will open the door to several new radioisotope applications, especially mineral applications useful to many developing countries.

MONITORING THE ENVIRONMENT

With the increasing public awareness of environmental problems has come a stepped-up effort to quantify them and to learn more about their interrelated ecological effects. The versatility of radioisotope technology has proved to be very useful in meeting these diverse new requirements. Only a few examples will be discussed here because a complete review was recently presented by Mott.[30]

To date, NAA of trace pollutants in air and water has received far more attention than other promising nuclear techniques. Several investigators[31,32] have demonstrated how the great sensitivity of NAA can be used to detect and follow trace levels of pollutants in air and water in a variety of areas. Experience has shown, however, that the cost of reactor NAA is seldom competitive with conventional analytical instruments for routine work where the sensitivity of the latter will suffice.

This limitation points up the significance of the capture-gamma NAA work recently reported by Trombka.[33] Using only 2 μg of ^{252}Cf with an output of 6×10^6 n/sec and a Ge(Li) detector, this investigator was able to measure down to a few parts per million of mercury in fresh water in the laboratory. This technique has also been incorporated into a bore-hole probe for subsurface mineral measurement,[34] and it is expected to be tested soon for pollution measurement in the field.

The spillage of petroleum and petroleum products in rivers, harbors, and coastal waterways is already a serious source of pollution of the marine environment. Bryan, Guinn, Hackleman, and Lukens[35] have recently evaluated the feasibility of using conventional NAA for tracing the source of such spills. They measured the trace elements in about 200 different oils from different producing areas of the world and concluded that seven of the elements found can serve as durable "fingerprints" to identify the source of oil slicks. They also found that these unique prints do not change appreciably when the oil is in prolonged contact with seawater. The responsible U. S. government agencies are presently comparing this nuclear approach with other possible techniques in an effort to establish an acceptable law-enforcement tool for this application.

XRF analysis is just beginning to prove its worth for pollution monitoring. Using a Si(Li) detector system, Rhodes[36] has demonstrated the ability to measure up to 15 elements simultaneously using filter-paper samples. The sensitivity attained in these measurements translates to an average of about 0.005 $\mu g/m^3$ of air—which is about 20 times as sensitive as the technique routinely used for air filter measurement today in the United States.

Portable radioisotope XRF analyzers are also finding use in meeting important pollution problems. Units are now in routine use in several U. S. cities for measuring the lead content in paint—especially old paint layers in tenement buildings. Recent investigations have detected many cases of lead poisoning in children from this source.

Accurate knowledge of the reaeration of rivers is necessary to assess their capacity to assimilate pollution. A new radioisotope technique for this purpose, first investigated by Tsivoglou et al.,[37,38] is rapidly gaining acceptance. It is the first direct method of

measuring how well a particular river recovers oxygen from the air to replace that which is depleted by bacterial degradation of organic pollutants in the water.

In its simplest form, the Tsivoglou method involves the simultaneous release into a stream of two radioisotope tracers—tritiated water to provide an accurate measure of flow rate and dispersion, and ^{85}Kr (in a water-soluble clathrate form) to provide the desired information on solution gas losses to the atmosphere. A downstream measurement of the relative concentrations of the two radioisotopes determines the amount of ^{85}Kr loss, which is then used to calculate the desired oxygen-exchange information using established solution–gas relationships. A dye is usually used with the radioisotope tracer for flow-rate measurement and visualization.

More than 200 million tons per year of pollutants are currently estimated to be discharged into the air over the United States. Several isotopic devices and techniques are now under development by the USAEC to measure and trace these waste materials to aid the national control of all emissions. For example, a sulfur-isotope-ratio technique[39] being developed at BNL is proving to be very valuable for studying the dispersion and fate of pollutants in the atmosphere, especially those from fossil-fuel electric-power plants. Although sulfur dioxide is the major air pollutant from stationary sources in the United States (more than 25 million tons per year discharged), relatively little is known about its movement and fate once released into the atmosphere. This project, now in the field investigation phase, relies heavily on two isotope techniques to measure and follow the intricate chemical and physical exchanges that take place—all the way from the fuel burning through plume dispersion. A tritium beta source is used to ionize treated samples of effluent gas and measure the SF_6 gas that is released to follow plume dilution. Mass spectrometry is used to measure the $^{32}S/^{34}S$ ratio, which has been shown to be an accurate indicator of the source of the sulfur.

Goodman and Donaghue[40] are developing a portable field instrument to inspect automobile exhaust for carbon monoxide, hydrocarbons, and the oxides of nitrogen. These major atmospheric pollutants are measured by counting the ^{85}Kr released by three kryptonated reactants, each of which is specifically reactive with one of the pollutants. Such a device will be widely needed by 1975 when new nationwide limits on these pollutants become mandatory in the United States. This analyzer can successfully measure concentrations that are only 1% of the 1975 limits.

Environmental Systems Under Development

Four additional environmental measurement systems that promise to have special use in developing countries are under development by the USAEC:

1. A profiling snow gage[41] with telemetering readout and control was installed last winter in the Sierra Mountains and functioned satisfactorily.

2. Flyover snow gages[42] installed at three sites last winter also gave satisfactory snow–water content data in field tests. This system uses a 3-Ci ^{137}Cs source on the ground with synchronized radiation and photographic systems on the aircraft to measure the radiation attenuated by the snow.

3. The radioisotope sand-tracing system developed by ORNL[43] may be of great interest to coastal countries. This system utilizes the radiation signal from a scintillation detector in a "rolling" cylinder on the sea floor and a small computer on board ship, which is programmed to plot the movement of tagged sand while it is being detected.

4. An NAA system for measuring minerals in situ on the ocean bottom is under evaluation by Perkins[44] at the Pacific Northwest Laboratory of Battelle Memorial Institute. The system employs a 1.8-mg ^{252}Cf source and a 50-cm^3 Ge(Li) detector. Several elements of interest can be measured at concentrations useful for mineral exploration, including vanadium, manganese, indium, gold, and silver.

INDUSTRIAL RADIATION PROCESSING

About 50 industrial radiation processing facilities are now in use in the United States—40 using accelerator sources and 10 ^{60}Co. The amount of cobalt installed in these facilities is about 9 MCi (three times the amount at the time of the Third Geneva Conference). Installed accelerator power for the same use is about 710 kW, or the equivalent of about 50 MCi. A recent review paper by Ballantine and Harmer[45] gives a complete status report on applications of both of these sources in the United States.

The routine use of gamma radiation to sterilize disposable medical supplies has grown rapidly in the United States; three completely automated gamma sterilization centers are now in continuous operation. The technique is now well accepted as safe, practical, and effective.

Polyethylene oxide and a new (yet unidentified) flocculating agent are recent additions to the chemical products being produced with the aid of ^{60}Co gamma radiation. The largest use of accelerators continues to

be for textile processing, ion implantation, and plastic processing. The curing of coatings on plastics and metals became a major application recently with the startup of a large accelerator process at the Ford Motor Company.[45]

USAEC RADIATION PROCESSING PROGRAM

The emphasis in the USAEC radiation processing development program has changed somewhat since the Third Geneva Conference. Work has continued on radiation engineering to undergird the new industry and on radiation chemistry to aid in the search for new products and processes with economic potential. However, much greater emphasis is seen today in areas of product-application and -evaluation studies. Extensive product-testing programs are now under way in concert with potential industry and government user groups. This change has occurred naturally as new product possibilities emerged from the more fundamental aspects of the program. Indicative of this change is the fact that seven other government agencies, plus one industrial association, are now involved in cooperative programs with the USAEC to evaluate various products formed by radiation.

Most of the interest stems from the remarkable properties of a series of polymer-composite materials which have been made with gamma irradiation. Wood–polymer combinations, the first of this new class of materials, are now completely in the domain of industrial commercial production.

Current USAEC research and development[46] is centered on concrete–polymer materials. A family of such composite materials has now evolved which has some remarkable properties far surpassing those of either constituent. For example, concrete–polymer compressive and tensile strengths are up to four times those of ordinary, untreated concrete; and resistance to adverse chemical environments is vastly improved. Compositional variations in this material are being developed and evaluated for potential use as housing panels, bridge decking, undersea submersibles, tunnel linings, breakaway sign posts, desalination-plant vessels, drainage pipes, and mine-wall shoring. In the evaluation of these applications, all polymerization processes are being investigated and radiation is used only where it seems to be technically and economically competitive.

Potential public-benefit applications of this technology are also being explored. Two noteworthy projects with this purpose are an examination of the possibility of recycling some of the 2000 tons of solid wastes which an average U. S. city of 1 million inhabitants produces each day. For example, polymer composites of methyl methacrylate, sewage waste solids, and concrete have been prepared with compressive strengths up to 11,000 psi, which is more than twice that of ordinary concrete.

Another waste composite material being evaluated at BNL is a glass–polymer composite made from crushed discarded bottles mixed with 6 to 7 wt.% methyl methacrylate (see Figs. 1 and 2). These glass products exhibit compressive strengths up to four times those of ordinary concrete. Several formidable problems remain to be solved prior to wide-scale use of these materials, but all possibilities are being evaluated in view of the growing disposal problem.

FOOD IRRADIATION

From its inception, food-irradiation research in the United States has been carried out under dual sponsorship, with the USAEC evaluating the role that lower radiation levels—generally less than 1 Mrad—can serve in shelf-life extension and disinfestation and the U. S. Army concentrating on the use of high levels of radiation to sterilize foods for long-term storage.

The USAEC program has recently been focused on short-term preservation of three products (strawberries, papayas, and haddock) in an effort to test and evaluate the market acceptance of the technique in the United States as soon as possible. Detailed studies are now in progress to obtain the data needed to petition the U. S. Food and Drug Administration for approval of their unlimited human consumption. These three particular products were chosen for technical as well as economic reasons. Each represents a family of products with similar preservation problems: Irradiated strawberries represent a variety of fruits which are susceptible to rapid decay; papayas will test the combined value of insect disinfestation and preservation; and the haddock test results will apply to many foods whose shelf life and taste are quickly affected by bacterial spoilage. A quite modest effort is also being conducted on low-dose radiation processing of retail cuts of fresh red meat for possible application in centralized meat-cutting operations.

The net reduction in funding which has accompanied this concentration of effort does not indicate a diminution in the USAEC's conviction of the practicability of the technology or the intention to demonstrate its commercial feasibility.

U. S. cooperation in international food-irradiation programs has grown in recent years in recognition of

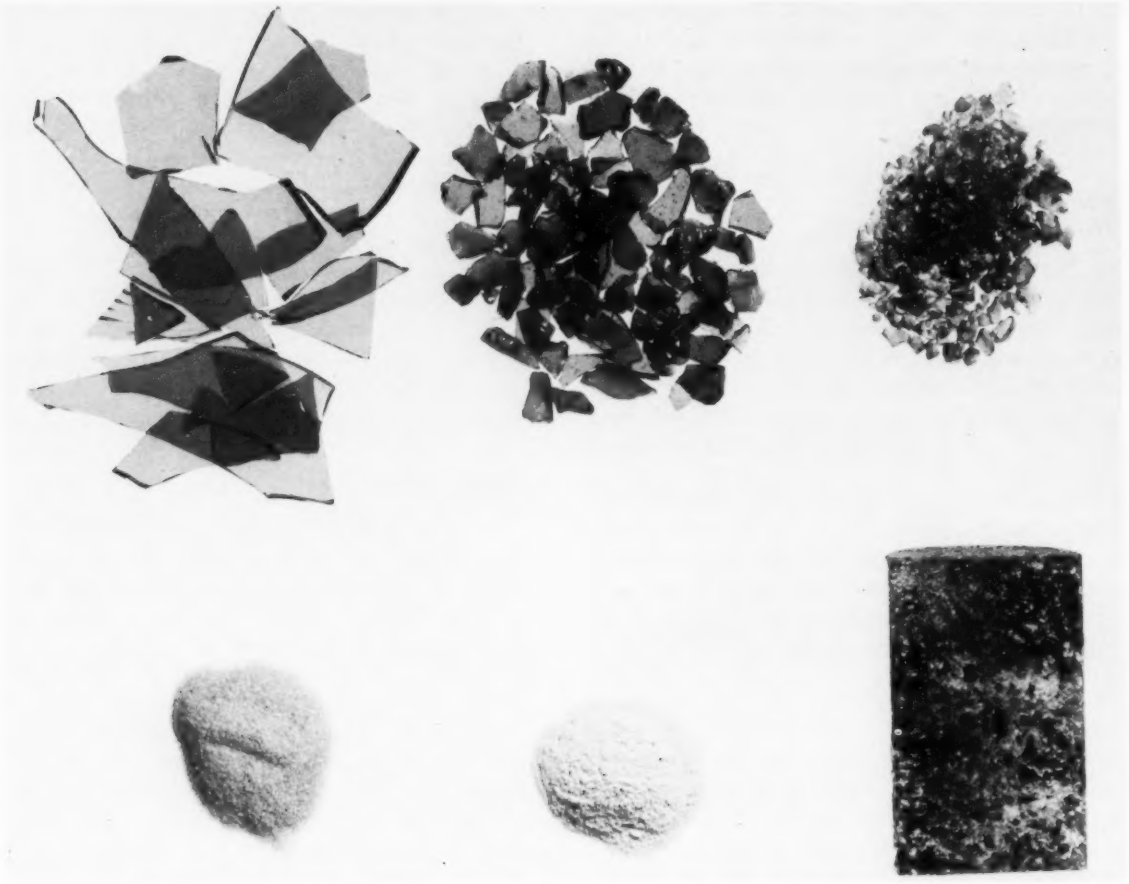

Fig. 1 Broken glass (beer bottles) of various size particles; lower right shows polymerized composite specimen.

the fact that many nations, especially developing nations, have a more immediate need for this technology than does the United States. For example, a recent International Atomic Energy Agency (IAEA) Panel hosted by the USAEC in Hawaii discussed the important international implications of the successful papaya disinfestation work recently carried out by groups in Hawaii.[47,48] Earlier this year, the United States joined 19 other nations in the International Food Irradiation Project, a cooperative effort to share the lengthy and expensive feeding studies normally required separately for each country.

In addition, several irradiators have been loaned to various countries around the world as an aid to their national research programs in this area. Of course, many U. S. food-irradiation experts continue to cooperate with researchers throughout the world, especially through the IAEA Regular and Technical Assistance Programs.

POLICY CONSIDERATIONS

Before concluding, a discussion of a few of the factors that influence and guide the USAEC isotopes-development activities seems appropriate. Foremost among these factors is the changing priority of public-benefit requirements. Scientific initiatives in the United States today are very responsive to the public interest. The many developments described earlier demonstrate this in the case of environmental pollution problems. Other national priority areas that require continued attention in this way today are criminalistics, space exploration, oceanography, and natural-resources requirements.

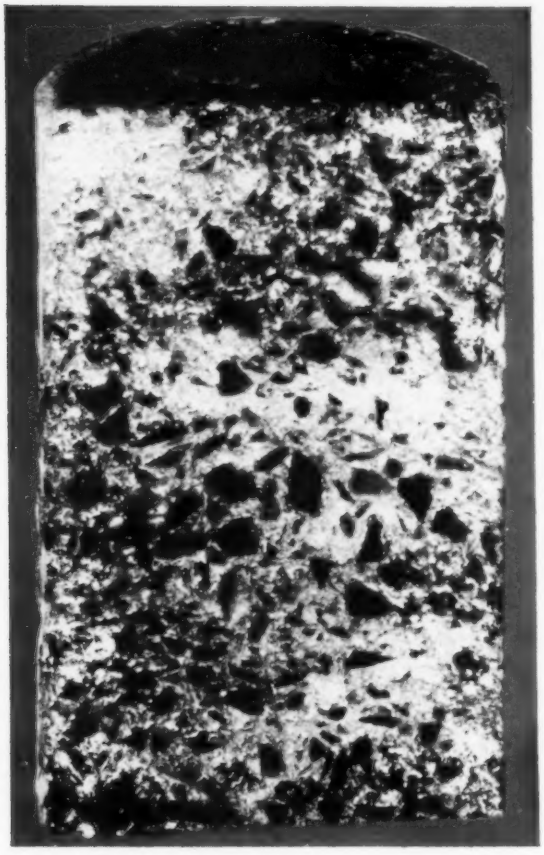

Fig. 2 Refuse–polymer composite containing broken glass (beer bottles) and polymethyl methacrylate.

Another important factor guiding the course of federally sponsored radioisotopes and radiation effort in the United States is the continuing government-to-industry transition of various items of isotope commerce and technology. Since its inception, the USAEC has followed a policy of encouraging industrial take-over of products and services at the earliest point when healthy competition in private enterprise is assured.

Over the past 10 years, the application of this policy has been very successful in the commercialization of many products and services. This is clearly seen in the area of radioisotopes production and distribution where the USAEC has gradually discontinued the supply of some 65 radioisotopes, as well as many related services, over the years. More than 100 private firms have come into being to carry out these activities.

As each new segment of the industry becomes established, it gradually builds its own research and development effort. This continuous transition requires frequent reassessment of national research and development programs and priorities so as not to duplicate work being conducted by industry. Through this self-imposed transition process, the AEC has, in recent years, gradually turned away from routine commercial radioisotopes activities to concentrate more on developments that undergird the technology as a whole, especially those which utilize the large and unique facilities and capabilities of its national laboratories. Of course, this ongoing research at the national level continues to benefit commercial activities indirectly by expanding the whole technology.

CONCLUSIONS

The pace of progress in radioisotope technology has quickened considerably since the Third Geneva Conference. Technical feasibility and economic value have now been amply demonstrated for industrial applications throughout the world. A new development initiative now under way has shown where and how this technology can also be used to solve a variety of public-benefit problems, including many worldwide pollution problems that require immediate attention.

The challenge for the future is clear. A concerted international development effort, similar to that already accomplished with industrial radioisotopes applications, is now needed to establish these new uses and bring them to bear significantly on these serious problems which are common to all mankind. (RHL)

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Section

I

Isotopes and Radiation Technology

Isotope Technology Development

^{252}Cf Neutron Activation for Remote Surface Analysis

By R. W. Perkins, W. A. Haller, H. G. Rieck, L. A. Rancitelli, and N. A. Wogman*

(Summarized by Martha Gerrard)

Supplementary Keywords: *space; activation analysis; chemistry, analytical; ocean; land; source, neutron; instrument.*

Abstract: *The use of a ^{252}Cf neutron source for activation coupled with a Ge(Li) diode gamma detector was shown to be feasible for analyzing minerals on the ocean floor. Both laboratory and simulated in situ continental-shelf conditions were tested. This article is a summary of BNWL-SA-3803, a paper presented at the Neutron Sources and Applications Conference in Augusta, Ga., April 1971.*

Mapping of the mineral composition of terrestrial areas and of the ocean floor could be greatly simplified, and planet surfaces could be analyzed remotely, if methods were available for rapid in situ determination of the elements present. The procedures usually considered for multielement analysis—X-ray, arc, and mass spectrometry and alpha-scattering techniques—all involve rather complex instrumentation and have not been seriously considered for hostile environments such as the ocean floor or surfaces of planets with dense atmospheres.

An isotopic neutron source—^{239}Pu–Be—with a flux of 10^6 n/sec has been investigated for possible seabed analysis.[1] A ^{252}Cf spontaneous-fission source with a flux of 10^9 n/sec could have even greater potential, and the recent production of useful quantities of this nuclide, together with the development of very efficient high-resolution Ge(Li) gamma-ray detectors for measuring the neutron-activation products, has led to consideration of the ^{252}Cf–Ge(Li) diode system for in situ mineral analysis. Recent studies in our laboratory demonstrated[2] that with this system some 20 elements of commercial interest can be determined at concentrations well below those of economic value. Now, the heavy shielding needed because of the high radiation level from milligram-size sources has been obviated by the development of a subcritical assembly in which the source can be placed so that there is a 30- to 40-fold neutron multiplication.[3] Thus a 50-μg source could produce the same results as obtained here with a 2-mg source.

The work reported here was concerned with determining the feasibility of analyzing the beds of salt- and freshwater bodies as well as of land surfaces using a ^{252}Cf–Ge(Li) diode system. The favorable results obtained indicate that the technology may be applicable to analysis of surfaces of planets with dense atmospheres.

EXPERIMENTAL EVALUATION

Laboratory Tests

Measurements of gamma-ray spectrums of various types of ore and of simulated ore samples showed excellent photopeak resolution and indicated the fea-

*Battelle–Northwest, Pacific Northwest Laboratory, P. O. Box 999, Richland, Wash. 99352. Original report title: ^{252}Cf Neutron Activation for Terrestrial Sea Floor, and Possible Planetary Surface Analysis, published in *Neutron Sources and Applications,* Proceedings of the American Nuclear Society National Topical Meeting, Augusta, Ga., Apr. 19–21, 1971, Vol. 3, pp. III-20–29.

sibility of using this technology for analyzing both land surfaces and the beds of oceans and freshwater bodies. For these studies a 210-μg ^{252}Cf source was located at the bottom of a water-filled polyethylene tank, which served as a radiation shield. The radiation level at the surface of the shield was about 0.3 mR/hr.

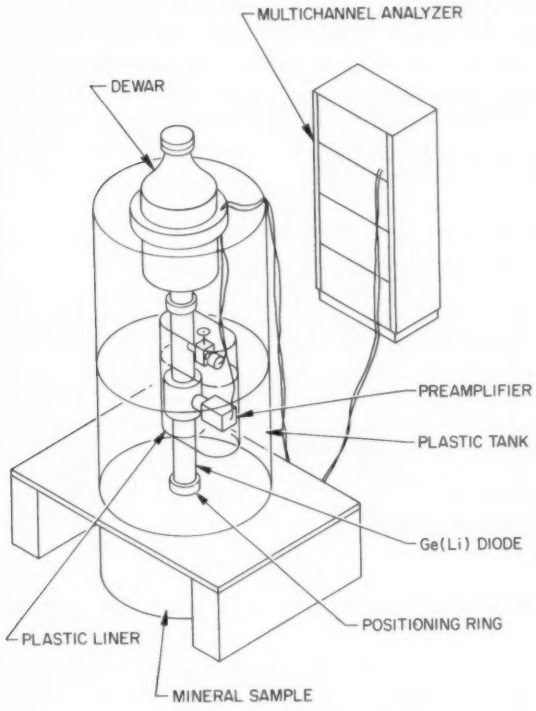

Fig. 1 Laboratory prototype of counting unit of ^{252}Cf neutron-irradiation facility for in situ seabed mineral analysis.

Bulk or simulated ore samples, representing essentially infinite sources, were irradiated for a short time and then were rapidly placed under a Ge(Li) diode detector (Fig. 1) for counting. To simulate the anticipated irradiation and counting geometries at the floor of ocean and freshwater basins, sea- or fresh water was placed around the source–moderator and the detector. Without the water present, conditions were those for land surface analysis.

Field Test

Following the successful laboratory demonstration, the technique was demonstrated in situ at the Battelle–Northwest Marine Research Laboratory at Sequim, Wash., using 200-lb batches of dunite, which contained 0.05% silver and 0.1% manganese. The samples were contained in cutoff 55-gal drums approximately 10 in. deep and 22 in. in diameter, which were placed on the tideland ocean floor during low tide. At high tide, when the measurements were made, the samples were covered with 4 to 5 ft of water. The source was positioned directly over the center of the sample, and irradiation times of 120 sec followed by a 30- to 40-sec decay and an in situ counting time of 200 sec were used. The concentrations of manganese and silver, as well as those of magnesium, aluminum, and vanadium, were easily measured from the photopeak areas (Fig. 2). There was not a detectable photopeak from ^{24}Na, and that from ^{38}Cl (37 min) was relatively small. This confirmed our laboratory ob-

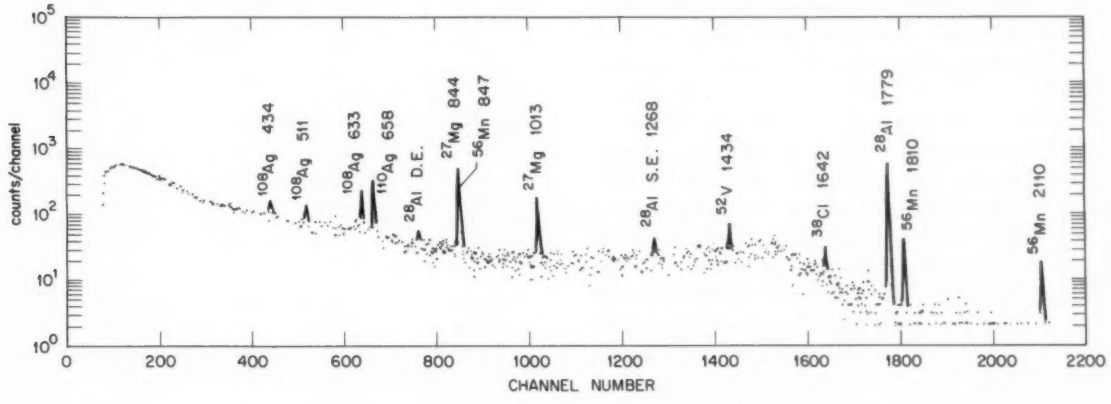

Fig. 2 Gamma-ray spectrum of 58-cm-diameter, 25-cm-thick dunite sample (Ag content 0.05%, Mn content 0.1%) on the ocean floor; 120-sec irradiation with 210-μg ^{252}Cf source, 36-sec decay, 200-sec counting with a 50-cm^3 Ge(Li) detector.

servations, which indicated that induced ^{24}Na and ^{38}Cl should not significantly interfere with ocean-floor mineral analysis. The elements that could be measured in this setup presumably could be determined with similar or even better sensitivity using a neutron multiplier that provides a flux equivalent to that of a 5-mg ^{252}Cf source.

The sensitivities with which the various elements in mineral samples can be measured with 2-mg ^{252}Cf sources were determined in a laboratory mockup arrangement (Fig. 3). The 2-mg ^{252}Cf source was near the bottom of a 12-in.-diameter by 12-in.-high paraffin moderator, which was centered at the bottom of a 6-ft-diameter by 7-ft-deep polyethylene tank in a 15-ft-diameter plastic swimming pool. The 0.5-in.-thick plastic bottom of the tank plus the 0.5 in. of aluminum separates the ^{252}Cf source holder from the samples. No gamma or neutron flux could be observed at the edge of the pool or the surface of the water, although about 20 mR/hr was observed at the sample-channel opening. The mineral samples to be analyzed, contained in 10-in.-high by 22-in.-diameter cylinders, were placed directly under the source for irradiation.

The sensitivities determined with this apparatus for 16 elements, based on the use of a 1.8-mg ^{252}Cf source and a 50-cm^3 Ge(Li) diode detector system (Table 1), were about the same as those observed in our laboratory mineral-assay facility.[2] These sensitivities were determined for seawater-saturated dunite containing known amounts of the elements of interest; however, several actual mineral samples have also been measured with sensitivities indicated to be within the ranges shown in Table 1. In the tests, a 2-min irradiation was followed by a 30- to 60-sec decay and a 2-min count.

The sensitivity for element determination on the floor of freshwater basins is only slightly better than for the ocean floor, while that on land areas is somewhat less because of the lower thermal-neutron flux which develops within a dry substrate. However, the rather wide range in sensitivities shown in Table 1 covers the sensitivities for all three types of substrates.

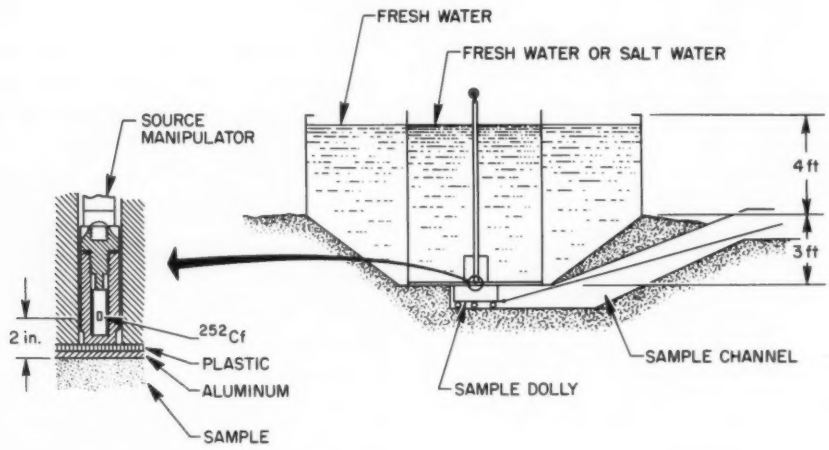

Fig. 3 ^{252}Cf irradiation facility for simulated seabed mineral analysis.

Table 1 Sensitivities for the Measurement of Trace Elements in a Simulated Ocean-Floor Matrix

Element	Isotope detected	Half-life	Detectable concentrations
Indium	^{116m}In	54 min	1–10 ppM
Selenium	^{77m}Se	18 sec	10–100 ppM
Silver	^{108}Ag	2.4 min	10–100 ppM
Titanium	^{51}Ti	5.8 min	10–100 ppM
Vanadium	^{52}V	3.77 min	10–100 ppM
Gold	^{198}Au	64.8 hr	10–100 ppM
Manganese	^{56}Mn	2.5 hr	0.01–0.1%
Aluminum	^{28}Al	2.3 min	0.1–1%
Arsenic	^{76}As	26.5 hr	0.1–1%
Cobalt	^{60m}Co	10.5 min	0.1–1%
Copper	^{66}Cu	5.1 min	0.1–1%
Molybdenum	^{101}Mo	14.6 min	0.1–1%
Antimony	^{122}Sb	2.8 days	1–10%
Cadmium	^{111m}Cd	49 min	1–10%
Magnesium	^{27}Mg	9.5 min	1–10%
Nickel	^{65}Ni	2.5 hr	1–10%

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High-Sensitivity Instrument for Beryllium Determination

By R. Cervellati, P. Monaci, and S. Sircana*

Supplementary Keywords: *source, neutron; industry, mining; chemistry, analytical; activation analysis; ^{124}Sb.*

Abstract: *An instrument for determining the beryllium content of ores by neutron activation, which contains a ^{124}Sb gamma source and has a sensitivity of 5 ppM or better, is described. This article is a summary of Italian Report RT/EL-(70)4, Sept. 14, 1970 (in English).*

Beryllium alloys are used in many fields, including metallurgy, aircraft and space engineering, and nuclear energy. This metal is stronger than steel but weighs only one-fourth as much, retains its strength at high temperatures, and does not rust or corrode. Its very small neutron-capture cross section prevents it from absorbing neutrons and makes it suitable as a container and moderator material in nuclear reactors and weapons. Disadvantages of beryllium are its brittleness, the toxicity of its compounds, and, at present, its high cost—about $150 per kilogram. However, the demand for it is continually increasing, and a sensitive analyzer was needed for field use in prospecting for new deposits—chiefly those in which beryllium ores are not easily identified—as well as for laboratory analyses.

This article describes a portable radioisotopic instrument developed by the CNEN for determining beryllium in ores with a sensitivity of at least 5 ppM.

PRINCIPLE OF OPERATION

The CNEN berylometer is based on the nuclear reaction ^{9}Be$(\gamma,n)^{8}$Be, the gamma energy being supplied by a ^{124}Sb source. The energy threshold of this reaction is 1.665 MeV, the lowest of any nuclear reaction, with the next lowest (γ,n) reaction threshold being that of deuterium, 2.227 MeV. Thus gamma rays of energy between these two values can induce neutron emission only when beryllium is contained in the irradiated sample.

Antimony-124 was selected as the gamma source because its gamma radiation is chiefly between 0.6 and 2.2 MeV. Only 0.2% of the total gamma emission is greater than 2.27 MeV. The ^{124}Sb 1.69-MeV gamma radiation produces neutrons in the beryllium with an energy of 24 keV, the activity that is measured in determining beryllium.

The ^{124}Sb is obtained by reactor irradiation of natural antimony, which has an isotopic composition of 57% ^{121}Sb, 43% ^{123}Sb. The 60-day ^{124}Sb product is contaminated with ^{122}Sb (2.74 days), which is allowed to decay for several half-lives for safety and to lower the pulse pileup in the counters, although the total gamma energy from this isotope is less than the ^{9}Be threshold.

INSTRUMENT DESIGN

In the CNEN berylometer (Fig. 1) the mineral sample, usually as a powder, fills all or part of a prism-shaped box, which is 13.5 cm high, has a volume of 330 cm^3, and has an irregular hexagonal base. The weight of the sample is usually between 400 and 500 g.

Two ^{124}Sb sources are used, one on each side of the sample. Each is an antimony rod 5 cm long and 1 cm in diameter, encapsulated in aluminum and fit into a pencil-shaped brass container whose upper portion is filled with lead. This container is threaded at

*Comitato Nazionale per l'Energia Nucleare (CNEN), Rome. Original report title: A High-Sensitivity Berylometer. (Italian Patent pending, No. 51954 A/70.)

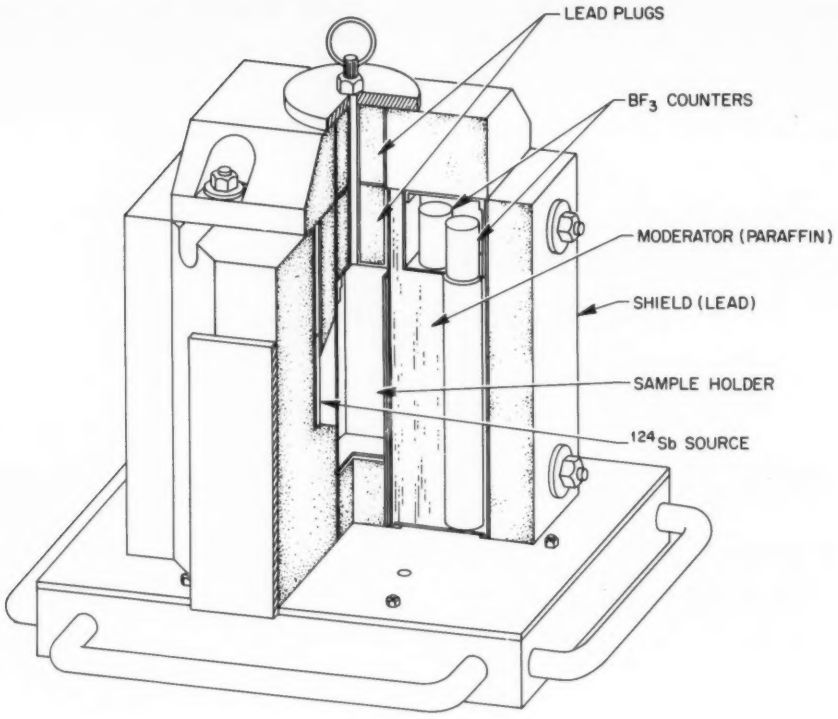

Fig. 1 CNEN berylometer.

the top for safe handling by means of a rod, 1.5 m long, also threaded at its end. The arrangement of the sample between two sources was considered to give a more uniform irradiation than the usual annular sample around a source.

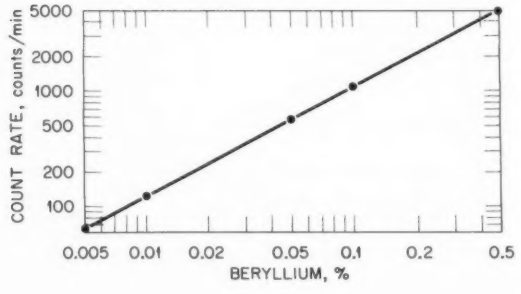

Fig. 2 Normalized (to 440-g sample) count rate of ^{124}Sb gamma-activated beryllium ore (beryl in calcium carbonate) as a function of percentage of beryllium. Two ^{124}Sb sources, 0.5 Ci each.

Two sets of BF_3 counters, three to a set, are placed beside the prism, and the six counters are electrically connected in parallel. Each set is embedded in paraffin and contained in a brass box. The paraffin between counters and sample is 2 cm thick—a compromise between the need for thermalizing enough 25-keV neutrons and for having the counters not far from the mineral sample. Sources, sample, and counters are surrounded by a thick lead shield, but between sources and sample there is only an air gap.

The neutron counter used has a count rate (sensitivity) of 5.2 counts/sec in a field of 1 thermal $n/(cm^2)(sec)$. Either a 12-V battery or house current is suitable for operation.

In a test with standard samples, the instrument responded linearly (logarithmic plot) to increases in beryllium concentration (Fig. 2). With two sources of 700 mCi each, a counting time of 30 min, and an ~400-g sample of medium-density ore, beryllium concentrations as low as 1 ppM could be detected.

(MG)

Forensic Neutron Activation Analysis of Paint

By H. L. Schlesinger, H. R. Lukens, D. E. Bryan, V. P. Guinn, and R. P. Hackleman*

(Summarized by R. E. Greene)

Supplementary Keywords: *activation analysis; activation, neutron; reactor chemistry, analytical; statistics; data handling; forensic investigation; coating.*

Abstract: *Characterization of paint samples was examined as a potential application of neutron activation analysis (NAA) in scientific crime detection. Paints were analyzed using neutron activation followed by gamma-ray spectrometry and computerized data reduction. One hundred fifty-six different paints taken from the environment according to a stratified random sampling model derived from an environmental survey were examined. Combinational statistics, which treat each element as an essentially independent variable, satisfactorily explained the observed combinations of element concentrations in the 156 paints. It was possible to predict, within the limits of distribution data provided by the data set, the probabilities of other combinations of concentrations of elements and of accidental matching of two different paint samples. The NAA method was shown to be an effective means of comparing paint specimens for forensic purposes. This is a summary of USAEC Report GA-10142, June 1970.*

Gulf General Atomic (now Gulf Radiation Technology) has conducted an 8-year program under contract to the Division of Isotopes Development, USAEC, to explore the usefulness of neutron activation analysis (NAA) in criminalistics. This work has been described in a comprehensive report[1] covering a 6-year period to May 31, 1968, a 1-year report[2] from June 1968 to May 1969, and a final report[3] to September 1970. A summary article for the entire period is being prepared for a subsequent issue of *Isotopes and Radiation Technology* by Gulf Radiation Technology.

Specialized reports related to this work have also been published and cover forensic neutron activation analysis of paper,[4] bullet lead,[5] gunshot residues,[6] together with one on paint, summarized below.

The study of NAA for characterization and identification of paint samples has proceeded in stages. A relatively small set of paints was first examined to determine if a sufficient number of elements could be quantitatively measured and thus provide some hope for definitive interpretation. Additional samples were analyzed to explore the variability of trace-element concentrations between (1) different aliquots from a common can, (2) samples from different cans of the same batch, (3) samples from different batches of the same paint, and (4) different kinds of paint.

Since the results of the early work were encouraging, a second phase was designed. Elements in paints appear to follow a log-normal distribution; therefore the second phase included development of multivariate normal distribution (MVN) statistics for application to NAA data and the acquisition of sufficient additional data to define analytical precisions, population densities, correlations between elements, etc., needed to implement the MVN statistical method.

The frequency of occurrence of painted objects in the environment was estimated by having 10 people in some common but not identical occupations record the painted objects they encountered in one 24-hr period. Only the type of object and the color, the color groups being selected to lead to the fewest number of ambiguous responses, were recorded. The responses were in turn reviewed and divided into nine object classes. The number of persons involved was small, but, within the practical constraints under which the study was pursued, the results should provide a reasonable basis for this study, which would also be confined to relatively few samples. A stratified random sampling model was derived from this survey.

One hundred fifty-six different paints (from motor-driven vehicles; exterior walls, doors, and windows; interior walls; furniture; appliances and tools; and other sources) were sampled in accordance with the model. Some samples were taken in duplicate and some from different parts of the same object. Samples were obtained by scraping the painted surface with a razor blade. All samples were analyzed by instrumental NAA on a purely instrumental basis (gamma-ray spectrometry and computerized data reduction). As in the earlier work, the TRIGA reactor was used for activation.

Conventional equipment and procedures were used, but this is the first study of forensic materials which the authors were aware of that routinely employed a Ge(Li) detector and 4096-channel pulse-height analyzer. The advance was most apparent in the

*Gulf Radiation Technology (formerly Gulf General Atomic, Incorporated), a Division of Gulf Energy and Environmental Systems, Inc., P. O. Box 608, San Diego, Calif. 92112.

number of elements detected. In an earlier study of about 80 paint samples using NaI detectors, 20 elements were found—in this study 37 elements were found. A less apparent but quite important advantage of the use of the Ge(Li) detector was the avoidance of errors from the undetected presence of a second component in an apparently pure photopeak. Arsenic was found as a trace element in a number of the samples. In earlier work, the 559-keV photopeak of ^{76}As was obscured by the greater activity from the 564-keV gamma ray of ^{122}Sb. The presence of arsenic thus implies that a small error is present in some of the antimony results obtained in earlier studies.

Since data from the 156 samples failed to fit a log-normal distribution, a combinational method was adopted wherein the distributions were pragmatically defined by the analytical data. The combinational statistics treat the observed distribution of the concentration of each element among the 156 samples as if it were completely independent from these distributions of the other elements. The distributions are defined by concentration ranges, and each range is given a code letter. The probability that a particular sequence of code letters will be associated with a randomly selected sample is obtained by multiplication of the probability of occurrence of the individual letters for the respective elements. It was found that loosely correlated elements can be used in the comparisons derived by this method, although only one of a set of strongly correlated elements can be accepted as a useful point of identification. Considering only the 10 most frequently observed elements and the average probability of occurrence in any of the concentration ranges, the average probabilities associated with any particular combination become smaller with increasing numbers of elements, as follows:

Mn/Al/Na	8.75×10^{-4}
Mn/Al/Na/Br	8.75×10^{-5}
Mn/Al/Na/Br/Cl	6.75×10^{-6}
Mn/Al/Na/Br/Cl/Zn	5.9×10^{-7}
Mn/Al/Na/Br/Cl/Zn/Sb	4.25×10^{-8}
Mn/Al/Na/Br/Cl/Zn/Sb/Ba	3.25×10^{-9}
Mn/Al/Na/Br/Cl/Zn/Sb/Ba/K	5.4×10^{-10}
Mn/Al/Na/Br/Cl/Zn/Sb/Ba/K/Co	6.8×10^{-11}

Derivative computations with respect to (1) the probability that the code letter sequence of a given paint sample (from, say, a jimmied window frame) will be matched by a single random sample (hypothesizing, for example, that a paint specimen adhering to a crowbar is a random sample) or (2) the probability that the code will be matched by one of a large number of samples are quite straightforward.

In practice, the actual concentrations of each element in each sample must be inspected to make due allowance where a different concentration for an element in two paints happens to have the same concentration letter code—a possibility in view of the width of each concentration range. Also, allowance must be made for code differences occasioned by similar concentrations falling near the border between adjacent ranges.

Ten elements, each of which may be used as a point of comparison, are detected, on an average, in paint samples by the NAA procedure. The 15 most frequently observed elements—and therefore the most generally useful—are, in decreasing frequency of detection: Mn, Al, Na, Br, Cl, Zn, Ti, Sb, Ba, K, Co, Cr, Ta, Ca, and W. It is extremely unlikely that the first five of these elements in two samples will have the same concentration unless the paints are of the same manufacture.

Given that the first five or six elements in two samples have the same concentrations, within normal intrabatch variabilities for those elements, the similarities or differences in concentrations can be examined with respect to the background data obtained in this study to ascertain, with a high degree of reliability, whether the two samples are from a common batch or from different batches. If they are from the same batch, a reasonable estimate can then be made as to whether the two samples came from contiguous or noncontiguous surfaces. The accuracy of this last estimate can be improved by analysis of duplicate samples from the surfaces in question.

This method of calculation allows statistical probabilities to be applied in the interpretation of paint-comparison data in a fashion that seldom appears in the criminalistics literature, and the probabilities surrounding known and questioned paint samples can be determined objectively. There is no reason why the mathematical procedure could not be employed in any criminalistics study in which a number of parameters are measured with a known precision for a questioned and a known sample. The method has the virtue of being completely independent of the type of distribution frequencies involved. The use of population data to define population density distributions gives a basis for interpretation, and loose correlations between elements do not perturb the analysis since they are built into the defined distributions. Strong correlations

are not ignored, but the present approach is to use only one of a set of strongly correlated elements; there are enough data points to make this procedure feasible.

The data obtained in the second phase of effort by using NAA for element determination demonstrated the possibility of differentiating between paints and frequently between paints of the same color on different parts of the object. Identical paints from contiguous surfaces were clearly shown to be the same, although such samples were more variable than duplicate samples taken from a can of paint. Other techniques and NAA can usefully complement one another. However, the objectives of the program have been successfully met—a useful technique, based on NAA, has been developed for ascertaining whether two paints are the same or different beyond reasonable doubt.

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Nuclear Instruments in the Fight Against Lead Poisoning

Supplementary Keywords: *X-ray fluorescence; pollution; portable; ^{57}Co; ^{109}Cd.*

Abstract: *Two X-ray-fluorescence instruments that use ^{57}Co or ^{109}Cd as the source of exciting radiation for the determination of lead in paint in situ are described.*

Lead poisoning in small children, particularly those living in urban ghetto areas, is a matter of considerable concern to public-health workers.[1-3] The most common cause of this so-called "silent epidemic" is the ingestion of lead-base paint. The habit of putting whatever comes to hand—paint flakes, for example—into their mouths is shared by all small children but is especially bad with children suffering from malnutrition.

New methods of treating lead poisoning, such as the use of chelating agents, have decreased the death rate from lead poisoning in recent years, but the number of reported lead-poisoning cases has increased in many cities—for example, in 1961 in Philadelphia, 109 cases were reported, which was twice the number in any previous year; in 1969 in New York City, 727 cases were reported compared to 171 in 1959. Subsequent to nonfatal lead poisoning, there may occur mental retardation, optic atrophy, cerebral palsy, chronic kidney disease, and severe high blood pressure.

Legislation prohibiting the use of high-lead paint indoors has been enacted—for example, in 1959 in New York City. As early as the 1940s, lead began to be replaced by titanium as a paint pigment, and indoor use of lead paints has steadily declined. However, in old houses a surface layer of nonlead paint may be applied over older lead-containing layers, which may still flake off as the newer paint wears. It has been found that 40 to 80% of the slum dwellings in Baltimore, Philadelphia, and Minneapolis still contain dangerous amounts of flaking lead paint, and New York City is estimated to have 450 thousand apart-

ments where lead paint is a hazard. Other cities have similar problems.

Complete elimination of the lead-poisoning problem by immediate and massive slum clearance projects is obviously not feasible. However, if hazardous dwellings can be readily identified, they can be "de-leaded" on an emergency basis by use of Sheetrock, tape, new paint, etc. This would protect the children living there until more permanent measures could be undertaken. Also, these units could be given a high priority in any permanent cleanup program

A method for in situ determination of the presence of lead paint in either surface or deep layers would simplify the apartment-inspection procedure considerably. The X-ray-fluorescence technique, using a radioisotopic source to excite the characteristic K X ray of lead, is the basis of a portable instrument for determining lead in the paint on walls, windowsills, stair rails, etc., in dwellings. Two instruments devised for this purpose are described below.

The principle of a portable instrument using nondispersive X-ray fluorescence for analysis was described in an earlier issue of *Isotopes and Radiation Technology*.[4] Briefly, in the instruments described, the K X rays of lead, which have an energy of 73 to 87 keV, are excited by a radioisotopic source with a higher-energy gamma emission. The characteristic lead X rays from a deep layer of paint reach the surface with little attenuation and are measured by a counter that is a component part of the instrument package. The measured intensity of the radiation is contributed to by each successive layer of lead-containing paint through which the radiation passes. The recorded signal is therefore a function of the total amount of lead within the influence of the detection system. The L X ray of lead, with an energy of 10 to 15 keV, would not penetrate the many layers of paint found in the old buildings being examined. (MG)

TEXAS NUCLEAR X-RAY-FLUORESCENCE ANALYZER FOR LEAD

By P. F. Berry*

The Texas Nuclear X-ray-fluorescence analyzer for determining lead in paint layers was developed under a Division of Isotopes Development contract. It has a ^{57}Co source, which emits a 122-keV gamma ray. Coarse discrimination against backscattered and undesired X rays is afforded by electronic pulse-height selection, and fine discrimination by a pair of absorption-edge filters. The filter thicknesses are such that the transmitted radiation intensity is the same over the selected energy region except for the narrow "pass band" between their two absorption edges. One filter is of gold and the other of tungsten, which have absorption edges at 69.5 and 80.7 keV, respectively. These materials were chosen so that the pass band will bracket the energy of the 75-keV lead K X ray. Since electronic pulse-height discrimination is not required, problems of electronic instability—caused, for example, by wide fluctuations in temperature—are negligible. This is an important feature, considering the temperature variations likely to be encountered in going from house to house, especially in winter.

For the development work described here, the source strength was approximately 300 μCi, which was adequate but necessitated a measurement time of 20 sec per filter. The current version of the instrument[5] has a 1-mCi source, which cuts the measurement time to 3 sec per filter and allows 1.5 to 2 years between source replacements. The detector—a NaI(Tl) crystal scintillator—affords a large sensitive area for maximum detection efficiency and is both rugged and compact.

The source is located in the center of the detector aperture to provide maximum detection sensitivity with minimum source activity and is completely shielded until the probe is placed on the sample to be analyzed. When the probe is placed in position, a retractable pin is automatically depressed and the source shutter is swung aside. When the probe is removed from the surface, the shutter automatically swings back into position to cover the source. The radiation dose to the operator is virtually nil when either the shutter or the sample is in place, and personnel monitoring is not actually required for the use of the instrument. The dose rate from an *unshielded* 1-mCi ^{57}Co source is about 3 mR/hr at 10 cm.

Operation

When the radioisotopic X-ray-fluorescence analyzer is used (Fig. 1) for determining lead in paint layers, the optimum distance of the sample from the probe head is fixed by a spacer (Fig. 2), so that the measured count rate is maximum and is relatively unaffected by a sample displacement of ±1 mm or so. However, determination of lead is still possible at larger separations of the sample from the head, as, for example, with the

*Nuclear-Chicago Corporation, Texas Nuclear Division, P. O. Box 9267, Northwest Station, Austin, Tex. 78757.

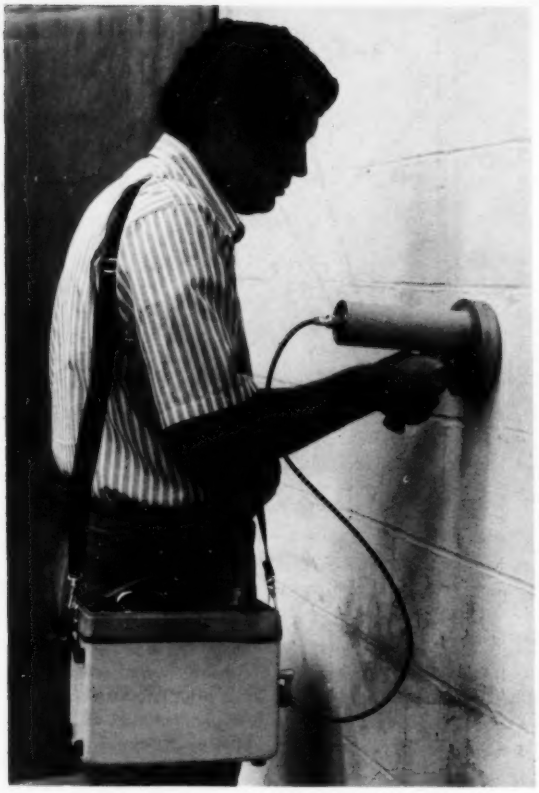

Fig. 1 X-ray-fluorescence analyzer.

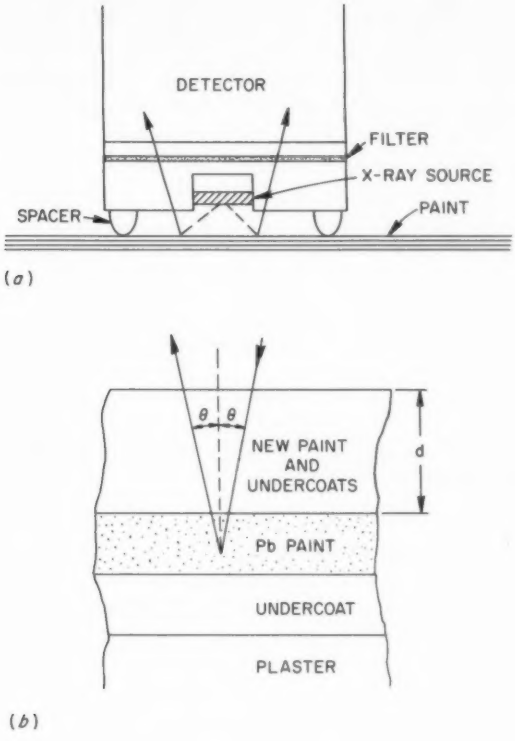

Fig. 2 (*a*) Measurement technique and (*b*) idealized sample arrangement for nondispersive X-ray determination of lead in paint layers.

molding beneath a windowsill, provided the source shutter pin is depressed.

Two radiation measurements are made, one with the gold filter in position, which gives essentially the backscatter intensity plus the lead X-ray intensity, and the second with the tungsten filter in position, which gives essentially only the backscatter intensity (85 keV). The difference between the measurements is proportional to the intensity of the lead X radiation and thus to the amount of lead in the sample examined.

The subtraction operation is accomplished by a differential digital scaler. With the gold filter in position, the scaler is caused to count in the "up" mode for a preset count time, the count being stored in the scaler memory. Then the tungsten filter is switched into position and counting is done in the "down" mode for the same preset time. Incoming pulses are automatically subtracted from the stored count, and, at the end of the counting time, the scaler stops and the residual count is displayed. With the 300-μCi ^{57}Co source, the counting time was 20 sec for each filter. A typical result from a sample containing lead is shown in Fig. 3.

Measurement Sensitivity and Calibration

The sensitivity of the radioisotopic X-ray-fluorescence analyzer for the determination of lead in paint layers is basically a function of the source activity and the time allowed for the measurement. The statistical deviation, ΔI, in the difference count $(I_1 - I_2)$ is given by

$$\Delta I = \sqrt{I_1 + I_2}$$

and the corresponding uncertainty in the quantity (Q) being determined is

$$\Delta Q = \sqrt{I_1 + I_2}/S$$

where S is the sensitivity $(\Delta I/\Delta Q)$ of the measurement. The measured fluorescent X-ray intensity is related to

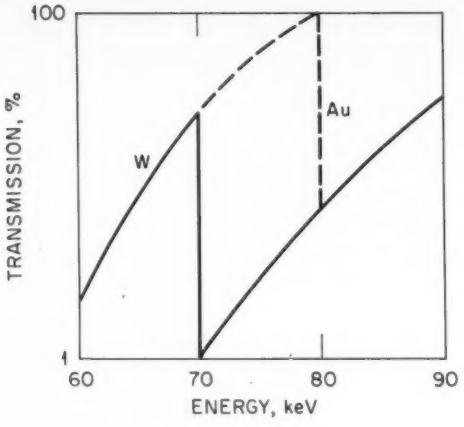

Fig. 3 Transmission of 75-keV lead K X ray through tungsten and gold filters.

the weight concentration of lead in the leaded paint and the average mass of lead per unit area of the leaded paint layer, with the relation between intensity and weight concentration being direct only for paint layers thicker than 1 g/cm^2. Typical painted surfaces seldom exceed 0.4 g/cm^2 total, with the leaded layer comprising only a fraction of this thickness. The response is then primarily a function of the product of weight concentration and mass per unit area, which is proportional to the weight of lead per unit surface area. Figure 4 shows the dependence on sample thickness and the reduced sensitivity in terms of % Pb at low values of mass per unit area. However, even for a thickness of 0.1 g/cm^2, which, according to surveys made in New York,[3] is the smallest value likely to be encountered in practice, the sensitivity is still adequate to measure 1% lead concentrations. The estimated detection limit is about 0.5 mg/cm^2 at the level of confidence chosen. The mg/cm^2 limit is a more meaningful indicator of toxicity than % Pb, but both units are in use and the instrument is therefore calibrated in terms of both. The use of % Pb is possible only if an assumption or additional measurement is made of the paint film thickness.

For the instrument to read in units of mg/cm^2, the sensitivity per unit weight is established with standard known samples, and the unknown value is readily found from a calibration curve. An alternative approach, which would have considerable merit in the use of the instrument in unskilled hands, would be to preadjust the timing period so that the displayed count would correspond directly to mg/cm^2 units. This is relatively easy to do and would require only monthly

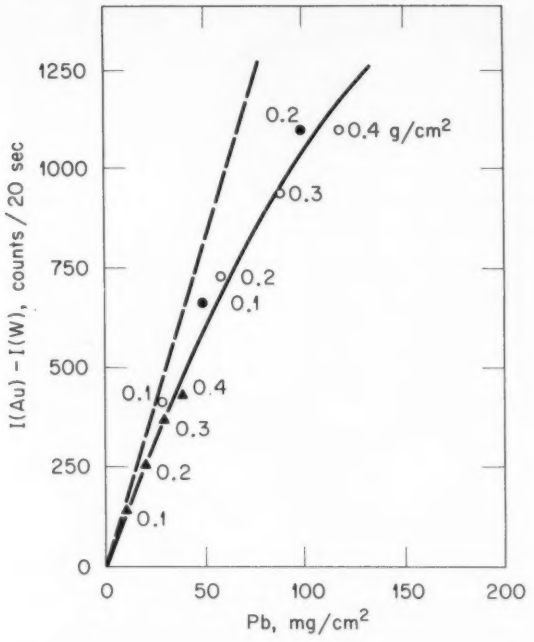

Fig. 4 Calculated transmission of lead K X rays (excited by 300 μCi of ^{57}Co) through paint layers of different thickness as a function of lead concentration in mg/cm^2. ●, 50% Pb; ○, 30% Pb; ▲, 10% Pb. Measurement time, 20 sec per filter.

readjustment (to allow for source decay) to maintain the calibration over the useful life of the source.

Correlation of X-Ray-Fluorescence Values with Chemical

The X-ray-fluorescence instrument described above was used to determine the lead in paint at a number of locations that had already been sampled for chemical analysis. In most cases only one determination per location was made, but, where the paint film thickness was obviously very nonuniform or where paint removal had been partially attempted, several determinations in the vicinity of the designated location were made. The locations included walls, doors, windowsills, and stair rails. Since paint thicknesses were unknown—and, in any case, varied widely—an average value of 0.2 g/cm^2 was used in the attempt to correlate the instrument reading with the chemical-analysis results.

A plot of the chemical results vs. X-ray-fluorescence results (Fig. 5) shows that in no case was a chemically established lead content underestimated by the radioisotope instrument. This is the most signifi-

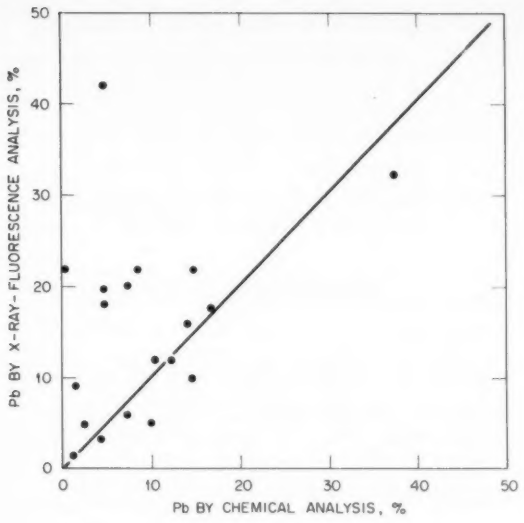

Fig. 5 Comparison of X-ray-fluorescence analysis with chemical analysis for field survey data. Sample thickness of 0.2 g/cm² assumed.

cant observation to be made from the data and requires no further comment. In many cases a high level of lead was indicated by the X-ray-fluorescence analyzer where a low level had been indicated by chemical analysis. However, this might be considered a "fail-safe" characteristic of the technique.

NEW YORK CITY HEALTH RESEARCH COUNCIL X-RAY-FLUORESCENCE ANALYZER FOR LEAD

By Gerard R. Laurer, H. D., Theo. J. Kneip, Merril Eisenbud, Roy E. Albert, and Norton Nelson*

The New York City Health Research Council X-ray-fluorescence analyzer was designed to use ^{57}Co, with a 122-keV gamma radiation, or ^{109}Cd–^{109m}Ag, with an 88-keV gamma radiation as the exciting source for lead X rays. Since the sensitivities obtained with the two sources were practically the same, only the simpler ^{109}Cd system is discussed here. The 180° backscatter peak of ^{109}Cd falls at approximately 66 keV, i.e., below the lead peaks (Fig. 6). An overlap exists in the 75-keV region, but the 85-keV K_β region is almost completely without backscatter interference. Thus with this source the single-channel-analyzer window can be set directly on the K_β peak for direct counting of the lead X rays. The remaining background has been found to be constant within expected statistical fluctuations, regardless of the backing material, at 5.0 ± 2.4 counts/min.

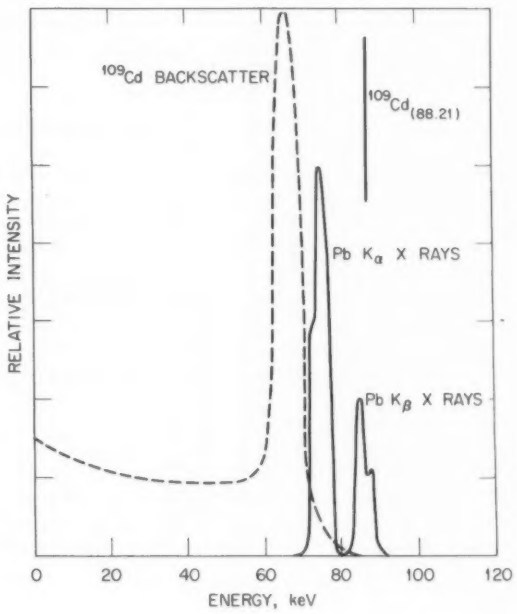

Fig. 6 Comparison of 180° backscatter radiation of ^{109}Cd and fluorescent X rays of lead.

Because of its greater sensitivity, a Ge(Li) detector was selected in preference to a NaI(Tl) detector (Fig. 7). A disadvantage of the Ge(Li) detector is the necessity of maintaining it at liquid-nitrogen temperatures. The liquid-nitrogen cryostat used for the prototype instrument had a volume of 3.5 liters, a holding time of 4 days; its weight of 17 lb, when full, somewhat limited its portability. However, a second-generation field design is now being produced by Canberra Industries, Inc., in which the detector, cryostat, and electronics are contained in a single module weighing approximately 20 lb.

The current pulses from the Ge(Li) detector are fed to a preamplifier mounted on the side of the cryostat and thence to an electronic module containing an amplifier, single-channel analyzer, and scaler (Fig. 8).

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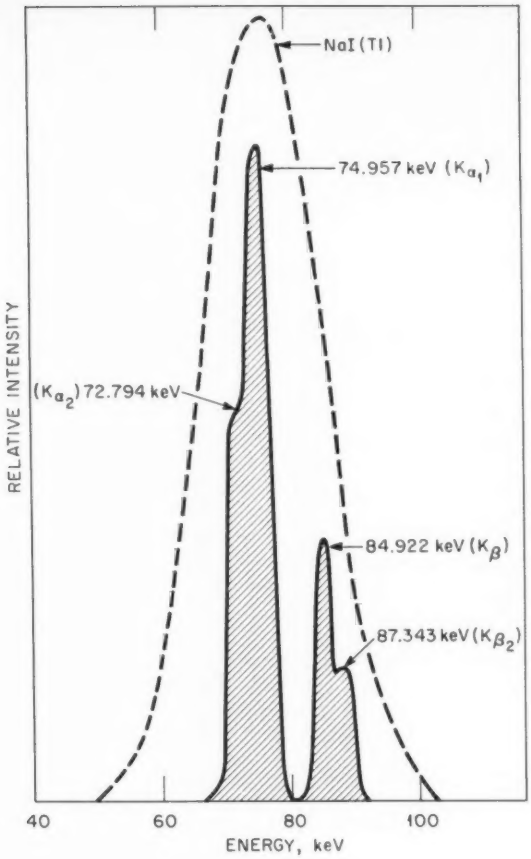

Fig. 7 Lead K X-ray spectra from NaI(Tl) scintillation crystal (dotted curve) and Ge(Li) (solid curve) semiconductor detectors.

Instrument Calibration

The detector response to sprayed lead-paint samples of known lead content was linear (Fig. 9) and was only minimally influenced by differing numbers of nonleaded overcoats. The data were obtained with paint sprayed on the surface of mock wall panels, simulating the surfaces expected to be encountered in a typical apartment: 1- by 4-ft wood forms covered with (1) wood lath, plaster cement, and plaster; (2) metal lath, plaster cement, and plaster; or (3) gypsum board and plaster. The wood-lath- and metal-lath-covered panels were divided into sections and painted. Each section had 11 coats of paint, 10 of which contained no lead. The other coat was a leaded paint, which was located at the bottom, the center, or the top of the other 10 coats. Paints with different lead contents (2.5, 14, and 64% of the dried paint layer) were used so that the detector response could be evaluated. The gypsum-covered panel was used only for comparison of unpainted background response with unpainted sections of metal-lath- and wood-lath-covered panels.

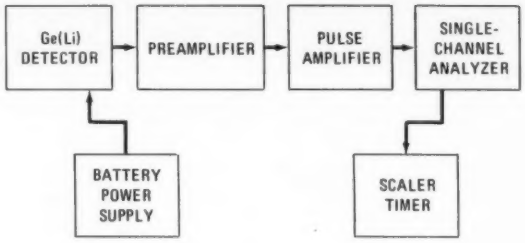

Fig. 8 Block diagram of X-ray-fluorescence instrument.

Field Test

The data from a field test on eight apartments showed lead found most frequently on wood surfaces and on bedroom, kitchen, and bathroom walls, with the highest levels generally on doors or windowsills.

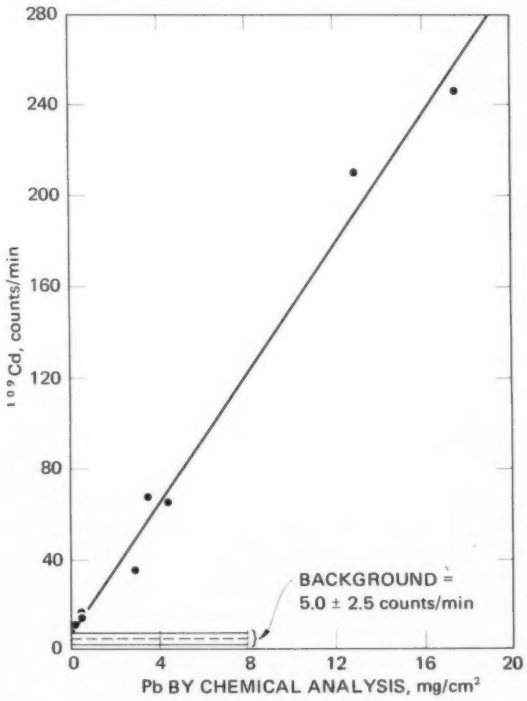

Fig. 9 Count rate for ^{109}Cd vs. chemical analysis of samples from prepared wall panels.

The results of the field test are expressed in milligrams of lead per square centimeter because the detector actually responds linearly to weight per unit area. Although the number of nonleaded coats does not affect the detector response, it does determine the weight of lead per weight of total paint, and thus the percentage of lead is not so useful for expressing the response of this type of detector system.

Radiation Dose from Use of Instrument

An evaluation of the dose rate at various positions while the instrument was in operation indicated that there is no radiation exposure hazard to either the operator or apartment occupant from its use. The dose rate 6 in. directly in front of the capped instrument was indistinguishable from background. At 1 ft from a wall surface with the instrument in operating position against the surface, it was 0.03 mR/hr, and at the surface of a hollow, wood-lathed, plastered wall directly opposite the source (i.e., transmission through wall with least attenuation), 0.25 mR/hr. At 6 in. directly in front of an uncapped source, it was 25 mR/hr, but, since the source is uncapped only when pointed at a wall surface, this exposure is not expected to exist in practice with the instrument in the hands of a trained operator. Transmission through a wall with least attenuation is unlikely to occur, but it may be considered the "worst possible condition" as far as the apartment occupant is concerned. Allowing for a 2-min exposure at this position, the total exposure would be $0.25 \times {}^{1}/_{30} = 0.0085$ mR. Radiation protection guides in current use allow a cumulative exposure of 500 mR for 1 year to an individual of the general population, and an exposure of 0.0085 mR is thus a negligible fraction of this total. The exposure due to backscatter of 0.03 mR/hr to the operator is also well below radiation-exposure limits of occupational exposure. These are 3 R/13 weeks, or, considering a 40-hr work week, approximately 6 mR/hr.

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STATE SURVEY OF PROCEDURES AND SPECIFICATIONS FOR THE USE OF NUCLEAR GAGES

The data from a questionnaire on the use of nuclear moisture–density gages in highway work, which was sent to 50 highway boards by the Highway Research Board Committee on Nuclear Principles and Applications, were reported earlier.* Evaluation† of the replies received indicated that users are finding the nuclear method a very flexible approach to the control of density and moisture in highway and associated construction, which can be tailored to the requirements of virtually any user. As with all testing, a certain level of competence will be required of the operator, but the requirements are no greater than for other methods of density testing.

Refinement of nuclear testing, which is already well accepted and whose accuracy is well established, will continue. However, because of the acceptance and general satisfaction with this test method as well as its present high level of development, it is not recommended that potential users postpone acquisition and use of nuclear gages from fear of obsolescence any more than they would hesitate to obtain any other type of test or construction equipment for that reason. The advantages of speed, accuracy, and economy warrant consideration of this test method for use by engineering firms, contractors, cities, and counties as well as by state and federal agencies. (MG)

*Highway Research Circular No. 121, February 1971 (Highway Research Board, 2101 Constitution Ave., NW, Washington, D. C. 20418); summarized in *Isotop. Radiat. Technol.*, 9(1): 21 (Fall 1971).

†Highway Research Circular No. 125, April 1971.

Sequential X-Ray-Fluorescence Determination of Particle Size

A patent has been issued in Britain* to the National Research Development Corporation, London, for an unusual application of a dual X-ray-fluorescence technique. The inventors claim that the intensity of fluorescence emitted by particles in a heterogeneous stream is dependent on the particle size; the degree of dependence is a function of the difference between the mass absorption coefficient of the whole sample and that of the particles containing the element being determined. Further, the dependence on size applies only for a certain particle-size range; this range can be determined if the fluorescent effect due to all the particles is distinguished from that due to the concentration of the fluorescent component of the particles in the fluid. This is achieved by measuring the fluorescence intensities of two separate beams of radiation having different energies (Fig. 1), chosen so that one beam will give a marked particle-size effect and the other will give only a negligible effect.

In the example given, the mean size of hematite particles contained in a slurry in water is determined with a $^{3}H/Zr$ source and a ^{109}Cd source. Bremsstrahlung from the ^{3}H excites the iron K X rays very efficiently, and the 22-keV X rays from the ^{109}Cd excite the iron with low efficiency. Calibration curves

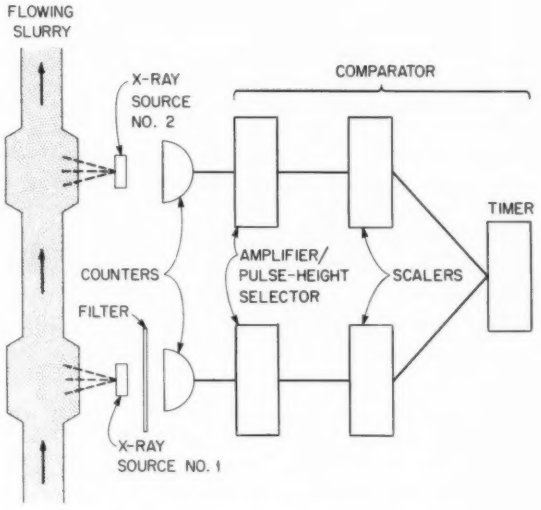

Fig. 1 System for determining particle size by X-ray fluorescence. Effect of X-ray source No. 1 is very particle-size dependent, and the filter is necessary to prevent backscattered radiation from reaching the detector. Effect of X-ray source No. 2 is not particle-size dependent.

are used to compare the output and deduce the particle size by interpolation. The apparatus can be used only where the composition of the solid particles can be controlled within limits that do not cause the fluorescence intensity of the X rays to vary significantly.

(FEM)

*Method and Apparatus for Determining the Mean Size of Given Particles in a Fluid, British Patent No. 1,193,840, to K. G. Carr-Brion and D. A. Jenkinson, National Research Development Corporation, London, June 3, 1970 (filed Sept. 20, 1967).

Total Pollution System Monitoring (TOPOSYM)

By Charles O. Badgett*

Supplementary Keywords: *measurement and control system; industry; pollution.*

Abstract: *The TOPOSYM (Total Pollution System Monitoring) concept is described.*

*General Manager, Process Industries Division, Industrial Nucleonics Corp., Columbus, Ohio.

Standards for air-pollution control are becoming increasingly stringent, and the need for new instrumentation to meet the pollution challenge is increasing correspondingly. However, development of such instrumentation has been slow, partly because of the slowness in both establishment of pollution-limit regulations and adoption of these regulations by

government agencies and partly because research and development budgets in this area have been small—e.g., 10% of the total instrument sales volume. The $\$10.5 \times 10^9$ instrument sales predicted for the current decade sounds large, but 10% of this comes to only $100 million annually, and the minimum cost to develop an instrument is $100 thousand—a minimum seldom achieved since the ill-defined standards require overdesign to arrive at a marketable instrument and a corresponding expenditure of 10 times this amount. This, together with the need for inexpensive instrumentation, has made instrument makers conservative about moving into the pollution-instrumentation market.

Good pollution-detection instruments must be both "people-oriented"—simple in construction, contain no chemical solutions, and capable of reliable, reproducible, and unattended operation over long periods of time—and "environment-oriented"—rugged in construction, stable to environmental conditions, sensitive, responsive to specific pollutants but able to measure several simultaneously, and capable of outputting real-time data that can be input to computers. Radioisotopic instruments meet many of these criterions. The radiation from a single radioisotope can excite the atoms of various elements, each of which emits its own characteristic radiation, thus permitting multiple-component determination by a single instrument. An isotope does not change with changes in environmental conditions such as pressure, temperature, vibration, or power failure, and instruments based on radioisotopes require no chemical solutions for operation.

Radioisotopic instruments can be used in a TOPOSYM (*To*tal *Po*llution *Sy*stem *M*onitoring) arrangement, the concept of which provides for controlling industrial pollution in the plant itself, i.e., in the process where the pollutant occurs or is formed or at the point where it might be released to the environment. Radioisotopic instruments can be used to determine the pollutant in the raw material, at any stage of the processing, and in the effluent and can be coupled with control instruments to stop the process whenever limits are exceeded.

The concept may be illustrated by the steps in a specific process, e.g., processing of coal. The mined coal is analyzed for sulfur and ash content, which can be done with a radioisotopic gage, and is then pulverized and washed. The particle size of the pulverized coal can be measured with radioisotopic instrumentation, and, to upgrade the coal, the heavier particles of ash and pyrites can be separated by a heavy-medium technique, the density of the heavy medium being monitored with a radioisotopic gage. The coal may also be upgraded with a hydrocyclone, whose operation is controlled by a radioisotopic density gage and electromagnetic flowmeter. If a premium price is to be demanded for coal from which the sulfur has been removed, another sulfur analysis, again with a radioisotopic instrument, can be made before the coal is shipped to the customer.

(MG)

Boron Tracer Technique Using a Neutron Gage

By A. Ariimuzi and T. Yamamoto*

(Summarized by Martha Gerrard)

Supplementary Keywords: *Tracer; material tracing; measurement, moisture; counting, neutron; industry, building.*

Abstract: *A method is described for tracing the movement of various materials—e.g., grout, fresh concrete, soil, and water. Boron is added to the material to be traced and is detected with a neutron moisture gage calibrated for boron.*

*Kajima Institute of Construction Technology, Kajima Corp., Tokyo. This article is based on Report No. 45 from the EURISOTOP Conference on Radiation and Isotope Techniques in Civil Engineering, Brussels, Belgium, Oct. 28–30, 1970.

In civil-engineering work a technique is needed for observing the movement of various materials, e.g., grout, freshly poured concrete, settling soil, and underground water. A procedure has been developed in which boron is added to the material whose movement is being observed and the presence of boron is detected with a neutron moisture gage. The technique offers no radiation hazard and can be applied in both laboratory and field work. Boron can be used in either organic or inorganic form. Disadvantages of the method are the

rather high boron concentration required and the interference of hydrogen.

The boron–moisture gage technique is described below.

PRINCIPLE OF METHOD

Because of the high neutron-absorption cross section of ^{10}B (3840 barns) in natural boron (20% abundant), boron can be detected by the effect it has on thermalized neutrons—namely, an attenuation that is proportional to the boron content. A neutron gage commonly used for measuring water can be calibrated for use in detecting the boron. Whereas a moisture gage determines water content by measuring the concentration of thermalized neutrons, the ^{10}B in boron "captures" these neutrons in proportion to the concentration of boron, thereby decreasing the concentration of the thermalized neutrons being measured by the gage. The effective volume of the neutron gage is somewhat smaller for boron than for moisture.

DETECTION OF BORON WITH NEUTRON GAGE

Calibration

The neutron moisture gage was calibrated for boron by adding known concentrations of borax solution to sand and determining the count rate with the detector. The ratio of the observed count rate to that of the sand sample without boron was found to decrease exponentially with increasing boron concentration (Fig. 1). The sand, which had a porosity of 40 or 50%, was saturated with borax solution in each case.

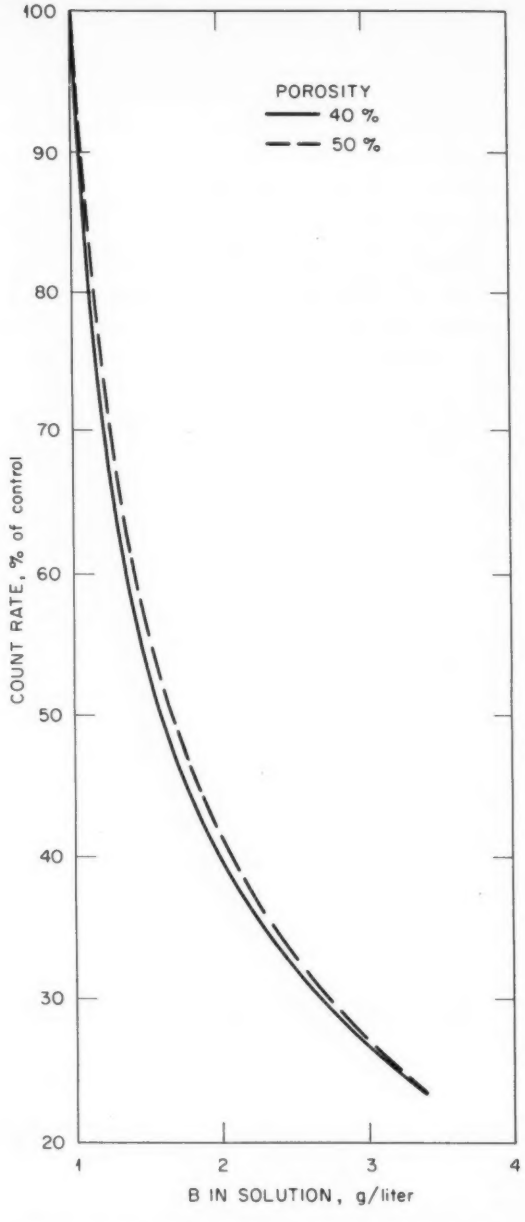

Fig. 1 Relation between counting rate and boron content.

Tests on Method

The boron technique was tested for tracing grouting, for determining soil settling, for observing the flow pattern of fresh concrete, and for tracing underground water.

Grouting. In civil-engineering work with grouting, it is important to know where the injected material will move in the particular type of soil under consideration, but the various techniques currently in use are complicated and expensive. The boron technique was tested on a sandy soil (10^{-1} cm/sec permeability), with a water level near the surface, which was being excavated. To make the soil impermeable to 4 m below the excavation depth, first a cement suspension was injected and then water glass to seal the finer pores. The grouting holes were 1.5 m apart, and there was one inspection hole for each 10 grouting holes.

Boron was added to both the cement and the water glass, and, after the two materials had been injected, the calibrated neutron moisture gage was lowered into

the inspection holes. The data showed that in one place the water glass had filled the part of the soil not treated with cement suspension while in another place the water glass had diffused into soil already filled with cement. Thus unpenetrated soil could be recognized and treated.

The penetrability of acrylamide and of urea resins was similarly tested by the boron–neutron gage technique.

Settling of Soil Under a Preload. The double-tube gage often used to determine soil settling is not reliable in long tests. For applying the boron technique to soil-settling measurements, a doughnut-shaped plastic tube filled with cadmium or boron was buried in the upper part of an 8-m-thick alluvial clay soil being reclaimed by loading sand on the surface. The location of the ring was determined, with an accuracy of ±1 cm, with the neutron moisture gage placed in a pipe that went through the doughnut hole. Measurements made at intervals showed the clay to be compacted with time.

Flow Pattern of Fresh Concrete. During the installation of an underground concrete wall in a bentonite slurry, using a tremie pipe, it was necessary to know the flow pattern of the concrete. Since the conventional method of using a dye would not satisfactorily show the state of the installation, the boron tracer method was tested. Before the concrete was poured, six access tubes were placed for the gages. Borax solution was added to the first and intermediate batches of concrete, and the boron was followed with a neutron moisture gage lowered into the holes. The results (Fig. 2) showed that the first batch covered the bottom slime but that the others formed a definite U-shaped pattern.

Tracing Underground Water. When an excavation was being made in a volcanic ash–sandy loam soil preparatory to building a dam, the boron tracer method was used for measuring the underground water flow rate and determining the soil porosity. Two casing pipes (20 m long, 2 in. in diameter) were installed 5 m apart. Ammonium borate (100 g) was placed in the upstream pipe and a neutron moisture gage in the downstream pipe. For the boron to reach the detection point required 90 hr. Comparison of the boron data with data obtained with an activable tracer (bromine as NH_4Br) showed a slightly slower flow rate by the activable tracer than that determined by the boron method. The effective soil porosity was calculated to be 12%.

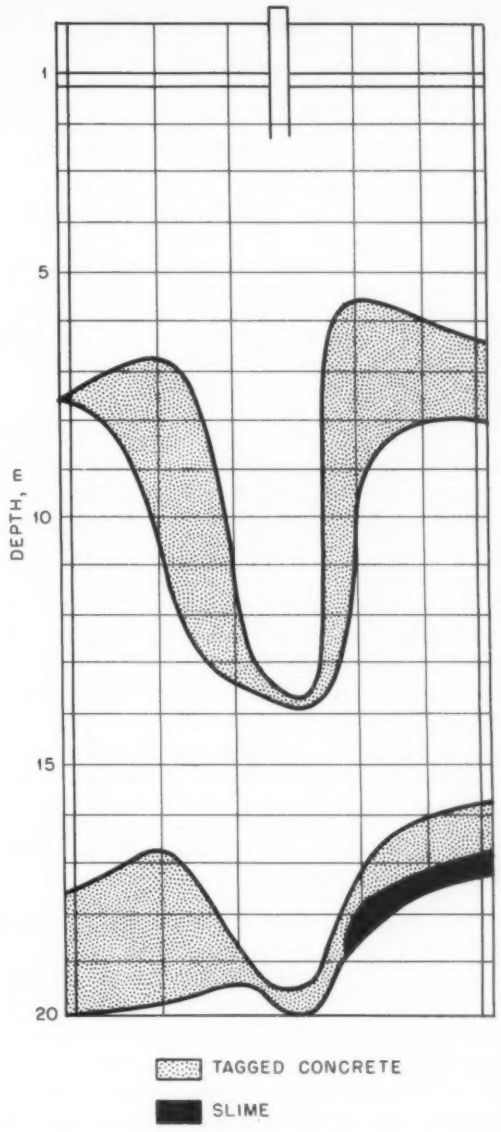

Fig. 2 Flow pattern of tremie-emplaced concrete in a bentonite slurry.

Radioisotope-Excited Light Sources

By P. Harteck and S. Dondes*

(Summarized by Martha Gerrard)

Supplementary Keywords: *luminescence; ^{210}Po; ^{90}Sr; ^{147}Pm.*

Abstract: *A 2-Ci ^{210}Po alpha source with helium gas produced a photometer reading of 10 mL, higher than that with any other gas studied. The beta sources ^{147}Pm and ^{90}Sr produced no significant amount of light with any of the gases studied. This article is a summary of USAEC Report RPI-3816-4, January 1970.*

Radioisotope-excited light sources are useful in remote places on land, at sea, and in the air—anywhere that installation and maintenance of ordinary light sources are difficult. A self-luminous sign on a superhighway near Phoenix, Ariz., which uses fission-product krypton gas enriched in ^{85}Kr as the beta-radiation source, has demonstrated the usefulness of such sources.[1] The light needed is 10 to 20 ft-L. Rensselaer, under contract to the USAEC Division of Isotopes Development, has also studied this application of radioisotopes, using the solid sources ^{210}Po, ^{147}Pm, and ^{90}Sr and mixtures of various gases. This work is reported here. Preliminary and background work were reported in Refs. 2 to 4.

TECHNIQUE USED

The production of light by irradiating various gases with sealed radioisotopic sources was studied in a Dewar vessel. The gases—He–N_2, Ar–N_2, N_2–CO, Ar–CO, Ar–N_2–CO, and, in the case of ^{210}Po, He–Ne, tank Ne, and tank He—were cooled with liquid nitrogen or oxygen to increase the gas density and to remove trace impurities. A tube of polished aluminum foil in the vessel reflected any light produced, for maximum output. The alpha source was 7 Ci of ^{210}Po, obtained from Monsanto Research Corp. in their NS-2 design (container 1 in. O.D. of stainless steel, 0.25 in. thick, on which ^{210}Po vapor was deposited and the deposit covered with a 0.00015-in.-thick stainless-steel window). The beta sources were 0.1 Ci of ^{90}Sr and 0.5 Ci of ^{147}Pm obtained from the 3M Corp. as microspheres set in a 1-in.-diameter disk and 40 Ci of ^{147}Pm and 8 Ci of ^{90}Sr obtained from Oak Ridge National Laboratory in specially designed containers. The light produced was measured with a photometer placed outside the quartz window (Fig. 1).

RESULTS

The only suitable light output was obtained with the 7-Ci ^{210}Po alpha source, which, with tank helium (containing 0.001% N_2), gave near contact a purple light with an intensity of 10 mL. With helium containing 0.01% N_2, the reading was 0.8 mL, and with neon, the light was red and had an intensity of 0.6 mL, which is somewhat higher than that of a 1-W neon bulb. Because of the cost of pure neon, helium containing 0.001 to 1% neon was tested, but, even when the mixture flowed through activated charcoal immersed in liquid nitrogen, results were not encouraging. The mixtures containing CO were investigated because of the formation of the excited CN radical, but they would not be useful in practice because of gradual decomposition of the CO.

With all gas mixtures studied, the 0.1-Ci ^{90}Sr and both ^{147}Pm beta sources gave light outputs too weak to be recorded by the photometer, and the 8-Ci ^{90}Sr source gave only a very low light output. The superiority of the solid alpha emitter to the beta emitters is probably due to the higher specific ionization caused by the short-range alpha particles. This result is not inconsistent with the demonstrated usefulness of the beta emitter ^{85}Kr, since the gaseous source is intimately mixed with the nonradioactive krypton and the specific ionization is higher than with beta particles from the discrete solid source.

The placement of quartz glass disks coated with phosphors, e.g., ZnS, in the gas stream at a distance greater than the alpha-particle path decreased the light intensity. Placement in the alpha-particle path caused them to glow sufficiently to be seen in normal light, but the light intensity decreased rapidly with conversion of the ZnS to Zn or ZnO.

The millilambert light production under these very preliminary laboratory conditions is not necessarily to be construed as maximum. The useful light output

*Rensselaer Polytechnic Institute, Troy, N. Y. Original report title: A Study of Improved Isotope Excited Light Source Techniques (Final Report).

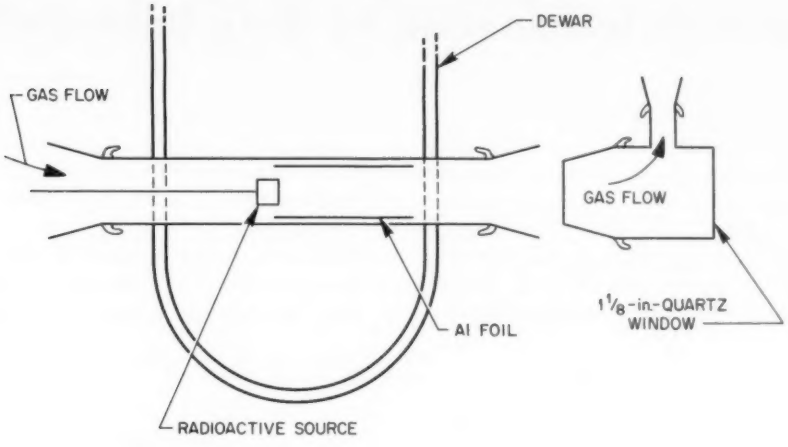

Fig. 1 Reaction vessel used in studying light production by radioactive sources.

could be increased by using a more highly reflecting surface, higher gas pressures, or sources made by impregnating glass fibers with a radioisotope or by introducing traces of an alkali metal to intensify the light emitted.

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TESTS AND EVALUATION OF LENSATIC COMPASSES MODIFIED WITH TRITIUM-SEALED SOURCES*

Supplementary Keywords: *military; industry, transportation; luminescence;* ^{3}H.

The use of sealed tritium sources to produce luminescence on the dials of compasses that are read with a lens and must be visible at night has been investigated. Nonsealed sources were originally considered, but they were a hazard in large storage depots because of loss of ^{3}H. For the sealed-source studies, the phosphor, ZnS, was incorporated in the paint that was applied to the markings on the compass dial, and the tritium gas was enclosed in a tube—straight in some designs and curved to fit the compass bowl in others—installed behind the compass dial and glass lens.

The radiological hazard with the beta-emitting tritium is less than that of the gamma-emitting radium, and the luminous life of the designs studied was greater than 8 years, vs. 6 months for the radium dials and 3 to 5 years for tritium paint. With a ^{3}H content of 50 mCi, for example, which produced an average luminosity of 64 μL, the compass directions could be read easily.

Work is continuing to increase the luminescence of the tritium–phosphor system. (MG)

*Abstract of Report 1997 (AD-726362), February 1971, by Robert C. McMillan and Judson M. Thurston, U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Va., supplemented by personal communication September 1971.

Dew-Point Determination by Beta Backscattering*

A new instrument was designed and constructed for determining the dew point from beta backscattering measurements. When dew, which comprises the light elements hydrogen and oxygen, forms on a metal surface, the effective atomic number of the relatively heavy metal is decreased, and hence the backscattering of any incident beta radiation is decreased. In the new apparatus (Fig. 1), a ^{14}C beta source is placed between the 1.4 mg/cm^2 window of a G–M counter and a gold plate that is cooled thermoelectronically. The source is located in a hollow in a piece of metal to prevent any direct beta radiation from entering the counter. In operation the plate surface is cooled, and the temperature, as measured by a thermocouple, and the backscattered beta count rate are recorded against time. When the temperature reaches the point at which dew begins to deposit on the plate surface, the count starts to fall. That this temperature is the dew point was confirmed by observation of the surface with a telescope. Dew deposition increases as the temperature falls, and the count rate begins to rise again only when the temperature is reached at which the dew begins to disappear. These two temperatures should, of course, be equal within the limits of experimental error.

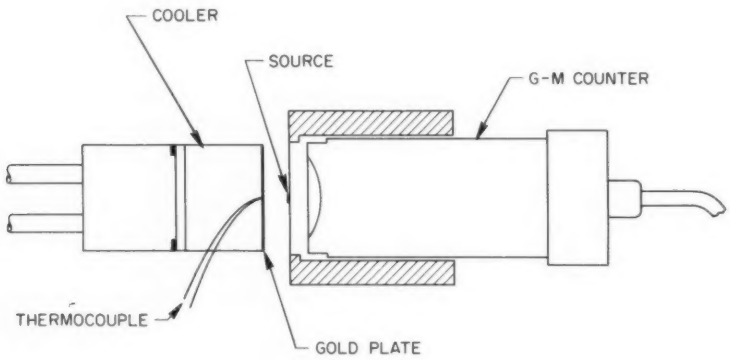

Fig. 1 Dew-point hygrometer based on beta backscattering.

Condensation nuclei formed by the radiation and the rough finish of the plate surface facilitate dew formation. Errors resulting from temperature rise due to illumination, which is essential for a mirror-type hygrometer, are not encountered.

(MG)

*Abstract of A New Method of Determining the Dew Point by Scattering of Beta Rays, by H. Kobayashi, *Rev. Sci. Instrum.*, **42:** 397-398 (1971).

^{244}Cm ALPHA PARTICLES MEASURE DELAY TIMES OF COAXIAL CABLES*

Supplementary Keywords: *source, alpha; measurement, other; spectrometry; standard; apparatus;* ^{242}Cm; ^{244}Cm.

Alpha particles from ^{244}Cm (and a small amount of ^{242}Cm) have been put to the unique use of measuring the electrical length of coaxial delay cables. In time-of-flight nuclear spectrometry, coaxial delay cables are used to make time calibrations; delay-time measurements accurate to 0.1 nsec are required. Delay times of manufactured sets of cables were determined by comparing the time required for

*Abstract of Time-of-Flight Measurements of the Electrical Length of Coaxial Delay Cables, by E. S. Pavlovskii, *Instrum. Exp. Tech. (USSR) (Engl. Transl.)*, **1970**(4): 1018-1019.

the propagation of a pulse along a cable with the time of flight of ^{244}Cm alpha particles in a known flight path. The alpha particles traverse a path between a start detector and a scintillator; the path distance is equal to the mechanical length of the coaxial cable. The difference between the pulse-propagation time and the alpha-particle time of flight is the delay time. Correction for this difference gives the correct electrical length of the cable. Some results are summarized below. The errors are mainly due to the apparatus drift. The systematic error ±0.08% is related to the error in energy losses of alpha particles in the emitter of the start detector. The accuracy achieved in the measurement of cable delay time with ^{244}Cm alpha particles makes it possible to measure a flight time in the range of 100 nsec with an error of only ~0.15%. (HPR)

	Cable				Connecting cables, 0.5 m		
	5 m	10 m	15 m, No. 1	15 m, No. 2	No. 1	No. 2	No. 3
Delay time, nsec	25.37 ±0.04	50.76 ±0.04	74.93 ±0.10	74.91 ±0.10	2.52 ±0.02	2.46 ±0.03	2.55 ±0.03

Systematic error ±0.08%.

ISOTOPES PROTECT CREDIT CARDS

Radioisotopes are used in a new system to detect any unauthorized changes on credit cards, drivers' licenses, and other personal identification papers. The system is the property of AB ID-Kort,* a Swedish firm co-owned by private industry and government departments (including AB Atomenergi).

In this system the identification card is made of photographic paper that contains trace amounts of a beta-emitting isotope with, usually, a 5-year half-life. On the front of the card is fine printing in colors that cannot be photographed and a plastic coating that is part of the film emulsion and thus cannot be pulled off. The back is also covered with printing and stiffened with plastic. The customer's photograph and signature are imprinted on the card and thus become an integral part of it. The authenticity of the card is checked by placing it in front of a specially designed Geiger counter. Any tampering with the card, such as attachment of a piece of transparent tape, causes a red light to flash. If the card is legitimate, a green light flashes. A further development of the system provides for computer comparison of the card with a master file.

The checking unit could cost as little as $80 in large orders and a card less than $1 in large quantities. About 200 thousand cards have already been sold in Sweden and 25 thousand in Denmark. (MG)

*Lilleholmsvägen 32, Box 43041, 100 72 Stockholm.

RADIOACTIVE TIMEKEEPING STANDARD*

Supplementary Keywords: *source, alpha; source preparation; industry, electronics; measurement, other; semiconductor; design; patent;* ^{235}U; ^{238}U; ^{237}Np; ^{239}Pu.

A long-half-life isotopic alpha source and a semiconductor are the chief parts of a radioactive timekeeping standard. The radionuclide is deposited in thin circular islands equispaced on a disk of shielding material. A circular mask having apertures in a configuration that matches the array of islands confines the alpha radiation to maintain it nearly monoenergetic. The alpha particles impinge on a surface-barrier or diffused-junction type of semiconductor to produce a relatively large number of output pulses. By electronic pulse-frequency dividers, the pulses are scaled down to a low number of control pulses, e.g., one per second, which are applied to an electronic or electromechanical time register to actuate or control the register to indicate time. Suitable alpha sources are ^{235}U, ^{238}U, ^{237}Np, and ^{239}Pu. Beta particles cannot be used because they are not monoenergetic; neither can gamma particles, for they cannot be handled in the confines of a small timepiece. (HPR)

*D. R. Koehler (inventor) and Bulova Watch Co. (assignee), U. S. Patent No. 3,582,656 (filed Mar. 21, 1968; granted June 1, 1971; see also British Patent No. 1,217,277).

ANGLE-OF-ATTACK INDICATOR USING A RADIOACTIVE SOURCE AND DETECTOR*

The angle of attack of a body traveling through air at supersonic speeds is indicated instantaneously by means of radiation reflected from the shock wave created by the body. On each of the two opposing surfaces of the body are mounted a radioactive radiation source and a detector (Fig. 1). The detector outputs are fed to a ratio computer and thence to a visual display device. (MG)

*Abstract of U. S. Patent No. 3,557,366 (E. D. Jernigan, Jr.), to Industrial Nucleonics, Jan. 19, 1971 (filed Apr. 17, 1967).

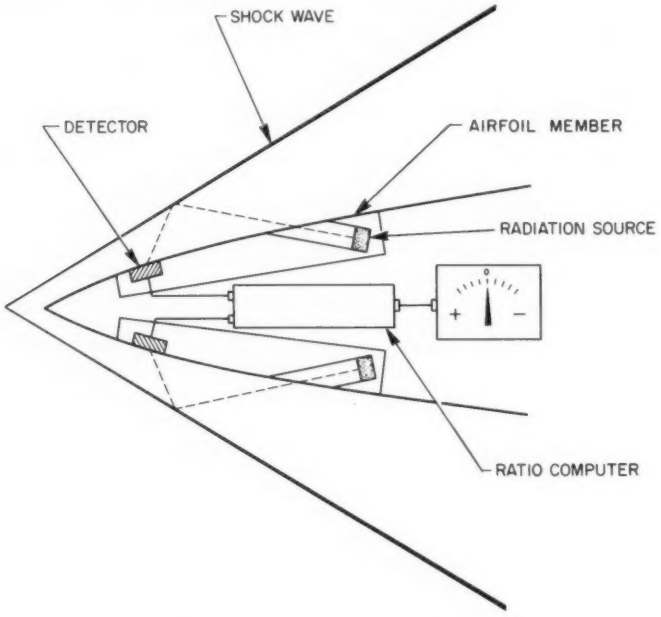

Fig. 1 Angle-of-attack indicator using a radioactive source.

TIMEPIECE DRIVEN BY NUCLEAR ENERGY*

Supplementary Keywords: *source, beta; energy source; direct conversion; industry, electronics; patent; design; measurement, other;* ^{63}Ni.

A U. S. patent has been granted on a novel timepiece, particularly a wristwatch, driven by nuclear energy. The device contains a beta source, for example, ^{63}Ni, that performs the dual function of producing the electrical power for energizing a counting circuit and for controlling a counting frequency or recombination frequency determining the advance of the timepiece. The timepiece contains, in addition to the beta source, a nuclear battery for direct conversion of the beta radiation into electrical energy, a window in the nuclear battery allowing passage of a beam of beta radiation, an electrical pulse detector in the beam of beta radiation, and a timekeeping electrical circuit controlled and energized by the radioactive source through the detector and battery, respectively. The rate of the timepiece is adjusted by a movable diaphragm (leaf) in the radiation beam. (REG)

*K. Adler and G. Ducommun (inventors) and Baumgartner Freres S. A. Solothurn, Switzerland (assignee), U. S. Patent No. 3,562,613 (filed Apr. 11, 1969; granted Feb. 9, 1971).

USE OF RADIOISOTOPES IN TRACING RESERVOIR LEAKAGE AT ANCHOR DAM

By R. L. Hansen and G. A. Teter, USAEC Report TID-25396, U. S. Bureau of Reclamation, July 1970.

In a cooperative project of the USAEC's Division of Isotopes Development and the Bureau of Reclamation, radioisotope tracers were used to determine the location of leaks in a reservoir. The reservoir contents were labeled with ^{3}H, and the water was sampled in drill holes around the reservoir; subsequently, ^{3}H was injected into leaks and sinks and the drill holes were again sampled.

The results indicated that reservoir water was being lost through a system of underground caverns that have opened to the surface (Fig. 1). The bulk of the water apparently leaks through an escape route, which was not accurately defined, but a small amount found its way to the normal groundwater system, causing a temporary buildup of the water table beneath the reservoir. The report describes the equipment and the procedures developed for use in obtaining these results—both of which may be applicable in other similar situations. (MG)

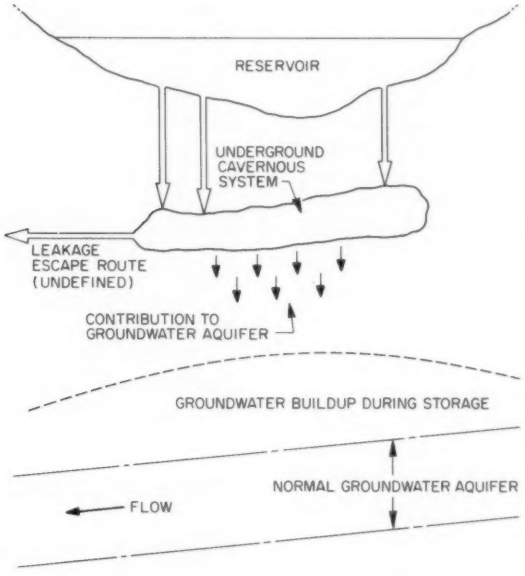

Fig. 1 Interpretation of the underground leakage system at Anchor reservoir.

Section

II

Isotopes and Radiation Technology

Food Irradiation

Radiation Pasteurization of Fresh Meat

By W. M. Urbain, G. G. Giddings, and W. W. Ballantyne*

(Summarized by F. E. McKinney)

Supplementary Keywords: *industry, food; food preservation; additive; comparison; material tracing; source, gamma;* ^{32}P; ^{60}Co.

Abstract: *Process development of radiation pasteurization of meats for centralized cutting is described. Beef that was phosphate-treated, irradiated to 100 krads, and stored at 38°F in vacuum for 18 days and in air for 3 more days was almost as acceptable to a consumer panel as unstored untreated beef. High dose rates from both electrons and* ^{60}Co *were compared. Irradiation in air led to discoloration; irradiation in vacuum up to 50 krads/sec did not discolor the meat. The action of phosphates in maintaining redness of meat was studied, but the results were inconclusive. This article is a summary of USAEC Report COO-1689-6, June 1971.*

Under a contract to the Division of Isotopes Development, the Department of Food Science and Human Nutrition, Michigan State University, has been studying the preservation of fresh meat by a combination method that uses radiation to lower microbial contamination, a phosphate solution to control drip, and vacuum packaging to preserve the typical red color of fresh beef. Results to date show that a dose of 50 to 150 krads delays microbial spoilage for at least 21 days at 38°F. Dipping the meat in a solution of sodium tripolyphosphate (TPP) or sodium hexametaphosphate "glass" reduces fluid exudation and aids in maintaining pigment stability by inhibiting pigment oxidation and enhancing pigment reduction when oxidation occurs. The meat is packaged in an oxygen-permeable film; then a group of these units are bulk vacuum packaged. This combination method can be used in bulk treatment and still yield normal red meat at the end of the extended postcutting storage period. Neither treatment is necessary if meat is held at 32°F or less, but industrial and home practice conventionally holds meat at somewhat higher temperatures. Irradiation at this low dose does not prevent spoilage—only delays it. In fact, under conditions of temperature abuse—storage at 50°F—irradiation at this dose is totally inadequate and spoilage occurs rapidly.

Experiments during the past year have concerned storage results evaluated by taste panels and by a combination of taste panels and chemical analyses [thiobarbituric acid (TBA)]; phosphate application methods; and color and pigment studies.

STORAGE STUDIES

Phosphate Dip and Irradiation of Fresh Beef

Taste panels were set up to evaluate the eating quality, especially flavor and juiciness, of fresh beefsteaks irradiated after being dipped in 10% TPP or in water or not dipped. The effects of TPP on color and water-holding are well known, but effects of TPP on flavor and juiciness have not been investigated although water-holding capacity and juiciness are known to be related. The steaks were wrapped and given a 100-krad dose from the ^{60}Co source and evaluated within 24 hr. Six panels of 24 members each evaluated meat for the following qualities: cooked color, odor, flavor, juiciness, and texture. Statistical analysis of composite

*Department of Food Science and Human Nutrition, Michigan State University, East Lansing, Mich. 48823. Original report title: Radiation Pasteurization of Fresh Meats and Poultry, Annual Report, Feb. 15, 1969–Feb. 14, 1970.

averages indicated no significant differences in overall quality between the three preirradiation treatments, although data suggest that phosphate-treated samples were slightly lower in quality for odor and flavor and slightly higher for texture and juiciness than the other samples.

Phosphate Dip, Irradiation, and Refrigerated Storage

Beef dipped in 10% TPP, irradiated, packaged, and held 21 days in vacuum followed by 3 days in air at 38°F was compared by two panels of 24 members each with beef held frozen for 24 days. Evaluations included beef dipped but not irradiated and irradiated but not dipped. The phosphated–irradiated beef received a relatively high overall quality score, presumably because of superior tenderness and juiciness.

Comparison of Vacuum Storage and Vacuum-Plus-Air Storage

Beef stored first under vacuum for 21 days and then in air for 3 days develops detectable objectionable flavors and odors whether irradiated or not. The period of air storage was assumed to be the time when the off-quality attributes developed. Beef was dipped and irradiated as previously described, but half was removed from vacuum storage after 18 days to be held in air 3 days and half was held in vacuum for the full 21 days. Taste panel tests held immediately after irradiation indicated inferior odor, flavor, and juiciness for phosphated–irradiated samples; but at final testing, samples stored in air for the final 3 days were rated lower in odor, flavor, and overall quality. Frozen controls were rated lower in juiciness because of excessive fluid loss during thawing. Irradiated samples held 21 days under vacuum received the best rating.

Lipid Oxidation Comparisons

Sensory evaluation data were compared to objective lipid oxidation measurements for correlation of the two tests. The addition of ascorbic acid was tested as a means of reducing lipid and other oxidations during the period of air storage. In the first series of experiments, taste panel evaluations were compared to TBA numbers (used as a measurement of oxidation). Samples were irradiated but not dipped or irradiated and dipped and were held 23 days under vacuum or held 18 days under vacuum and 5 days in air. There was a sharp increase in TBA values during the terminal aerobic period of storage, but there was little or no change during vacuum storage. The TBA numbers compared well with flavor score and to a lesser extent with odor and overall quality scores. This experiment was repeated with slightly different storage times, and the results were similar.

Ascorbic acid alone and in combination with TPP was added to beef as an antioxidant. Lipid oxidation was evaluated both by panel and by TBA analyses. In the first test, a solution of 2% w/v ascorbic acid with and without 10% w/v TPP was found to contain too high a level of ascorbic acid, and the steaks developed a greenish scum and a bitter taste after cooking. The TBA numbers did indicate a reduction in oxidation. Ascorbic acid was also readily observable to be effective in helping maintain a bright red color of the uncooked meat. In a second test, panel observations showed that a 0.5% w/v ascorbic acid solution protected the meat against oxidation and discoloration without causing greenish colors or bitter off-flavors. Refrigerated samples without ascorbic acid showed marked discoloration after 21 days in vacuum followed by 5 days in air. Even after 5 days in air, the TBA values of ascorbic acid–treated steaks were low. A third test, in which ascorbic acid was reduced to 0.25% w/v, did not show inhibition of oxidation, as measured by the TBA values. These experiments showed that the 0.5% ascorbic acid treatment is effective in lowering lipid oxidation (as measured by TBA values) and maintains color by keeping the pigment in the reduced, oxygen-binding state during aerobic storage. Additional work with taste panels is needed to confirm that the added ascorbic acid controls the off-flavors associated with lipid oxidation during periods of air storage.

PHOSPHATE APPLICATION METHODS

Although phosphate is usually applied to meat by dipping into a phosphate solution, a gas entrainment pumping device was tested for applying phosphate. The device forces two rows of seven needles each into the meat; on the injection downstroke, nitrogen gas at 20 psi enters the meat, and on the removal upstroke, phosphate solution enters the meat as a fine spray under 25 to 30 psi pressure. The amount of fluid delivered is controlled by the rate at which the needles are withdrawn from the meat. The commercial model of this device is completely automated; the amount of fluid added is reproducibly controlled. A hand-operated development model was used in this work, and the amount of fluid added varied. Pumping is of interest because dipping does not provide sufficient drip control for large pieces and because all cuts can be made from a previously pumped large piece, i.e.,

pumping could be a more efficient method of phosphate application.

Cuts were dipped for 1 min in 10% TPP and drained for 10 min or pumped with 10% TPP using the gas entrainment device and drained for 10 min. Meat was stored in gas-impermeable plastic bags for 1 week at 38°F. After storage, both the weight of the drained meat and the volume of liquid in the bag were measured. Data clearly show that pumping puts more liquid into the meat than does dipping; moreover, dipped meat released more fluid during storage. Pumping probably distributes the phosphate solution more evenly throughout the meat and improves the water-holding capacity of the meat, whereas dipping only affects a small surface thickness. This assumption was tested by comparing cuts dipped in phosphate solution with cuts from a large piece that had been pumped. The pumped meat absorbed much more fluid than the dipped, but released only half as much. However, the dipped meat showed better color retention. (This would be caused by a higher concentration of phosphate at the surface of the meat.)

A taste panel evaluated beef that had been dipped in a chilled solution containing 10% TPP and 0.5% ascorbic acid and beef into which the solution had been pumped by the gas entrainment device. Evaluation 3 hr after treatment showed that the controls were low in flavor and less tender and juicy than either dipped or pumped samples; there was a slightly lower overall score for the pumped–irradiated meat than for dipped–irradiated meat, but this was attributed to the interaction of greater moisture content and ionizing radiation. Pumped steaks generally exhibited a slightly spongy, more open texture because of the action of the needles and gas. In general, pumping is more efficient and more effective in retaining water-holding capacity, but dipping is better for color retention. Additional work is indicated.

COLOR AND PIGMENT STUDIES

The pigment in red meat occurs in three forms—oxymyoglobin, reduced myoglobin, and metmyoglobin. The concentration of all three forms was determined at the surface of meat both before and after irradiation by reflectance measurements with a recording spectrophotometer. The irradiation dose was 200 krads; dose rates of 5, 25, and 50 krads/sec from a 1-MeV electron accelerator and 0.05 and 0.5 krad/sec from a gamma source were used. There was an immediate increase in the amount of metmyoglobin formed at higher dose rates. Darkening was observed, caused by conversion from oxymyoglobin to both reduced myoglobin and metmyoglobin. The highest dose rate produced the darkest sample. After a 3-week storage period, the irradiated samples all had a similar amount of metmyoglobin—about twice that of the nonirradiated control. After 1 day of reoxygenation, measurements indicated only minor differences among samples, but visual observations differed in some respects from reflectance measurements—and the consumer does not use a spectrophotometer. Visually, the highest dose rates, 25 and 50 krads/sec of electrons, seemed to result in metmyoglobin levels too high for acceptability.

The previous experiment involved air packaging; another test was carried out with vacuum packaging. Reflectance spectrophotometry immediately after irradiation showed a slightly higher conversion to metmyoglobin only at the highest dose rate. Visual changes were slight. After the 3-week storage period, measurements showed that the higher electron dose rates may result in slightly greater amounts of oxidized pigment. After a 1-day reoxygenation period, the level of metmyoglobin was still highest in the samples treated with the highest dose rate of electrons.

The effect of oxygen in air on color changes was further evaluated by irradiating meat in packages that contained oxygen at more than 1 atm pressure. Electron dose rates were 0.55, 5, 10, 15, 25, and 50 krads/sec; gamma dose rates were 0.05 and 0.5 krad/sec. Reflectance measurements were obtained before and after irradiation; the results exaggerated the effects of the presence of oxygen during irradiation. The amount of oxidized pigment in irradiated meat was greater than that in nonirradiated controls, and the amount increased with dose rate. Visible darkening of the sample was observed at all doses.

Surface darkening caused by conversion of bright red oxymyoglobin to purple myoglobin or brown metmyoglobin was more noticeable with irradiation under oxygen than under vacuum.

Effect of TPP on Pigment and Color

The chief problem in the extension of shelf life and distribution time of centrally cut fresh beef is that of pigment oxidation to brown metmyoglobin. Vacuum packaging reduces the rate of oxidation, and application of various inorganic phosphates to slow fluid exudation causes a marked decrease in oxidation. Experiments were carried out to quantify some of the effects of inorganic phosphates on meats. Beef slices

were dipped, drained, vacuum packaged, gamma irradiated to 100 krads, and vacuum stored for 21 days at 38°F. Reflectance measurements were made before irradiation, after the 21-day storage period, and after a 1-day reoxygenation period. Surface *p*H of fresh meat and of meat after storage was also measured. The principal solution was 10% TPP, which has a *p*H of about 9.1. Solutions of reagent-grade ammonium and sodium hydroxide and tris-HCl and carbonate buffers were prepared with *p*H values in the range 9.0 to 9.2. Only the dip solutions containing phosphate resulted in favorable reoxygenation color, although the control was the most oxidized of all samples.

In another experiment, the dibasic form of orthophosphate, Na_2HPO_4, was compared to carbonate and borate buffers, NaTPP, and a commercial blend of phosphates. Samples containing phosphates were superior in color after reoxygenation. The borate buffer was better than the carbonate buffer or control. Results with dibasic sodium phosphate were inconsistent; it seemed to be faster acting than the TPP, which probably had to be hydrolyzed by meat phosphatases before affecting the color.

Effect of Dibasic Phosphate on Pure Myoglobin

Sephadex-purified oxymyoglobin was dialyzed to remove the buffer, and quantities of Na_2HPO_4 were added in molar ratios of 1:10, 1:1, and 10:1. The *p*H value was adjusted to give 5.6, 6.1, 6.5, and 7.0. Results showed that as *p*H was lowered, oxidation rates increased; effects were independent of phosphate/myoglobin ratio. Evidently, there is little association between phosphate and oxidation rate when myoglobin is in the pure form.

A radiotracer experiment was carried out to attempt to establish some relationship between inorganic phosphates and myoglobin. Small quantities of $Na_2H^{32}PO_4$ were added to myoglobin solutions that were held overnight at 40°F and then applied to a Sephadex column. Some radioactive phosphate was eluted from the column with the myoglobin fraction, showing a qualitative indication of association. Another experiment showed that a small amount of radioactive phosphate remained with the myoglobin after dialysis for 2 days. Attempts to quantify the possible ratio of association were not successful. The connection between phosphate and myoglobin in meat remains unknown.

CONCLUSIONS

Phosphate treatment increases juiciness and tenderness in both irradiated and nonirradiated beefsteaks. The combination of phosphate and radiation tends to decrease the acceptability score of the beef so treated. The significance of this effect needs to be investigated further. Phosphate concentrated at the surface may decrease the quality score, but minimizing the amount of added water may reduce this undesirable side effect.

A more serious problem is the development of an off-flavor during postvacuum storage by lipid oxidation. The addition of an antioxidant, ascorbic acid, appeared effective in reducing this oxidation, as shown by lower TBA numbers, but verification with taste panel data is necessary.

Application of phosphate by pumping, using a gas entrainment device, was markedly superior to dipping for increasing water-holding capacity, but dipping gave better surface color stability. Treatment with pumping, followed by a light phosphate spray after cutting, will be investigated.

Dose-rate studies showed that dose-rate effect applies only in irradiation in air. Rates up to 50 krads/sec had an insignificant effect during irradiation in vacuum.

Despite intensive study, the manner in which phosphates protect against surface discoloration remains unsolved.

METHOD AND APPARATUS FOR MARKING CASED CONTAINERS BY IRRADIATION OF SENSITIVE EMULSIONS*

A radiation-sensitive emulsion is applied on the end of containers for food or other products prior to packing in shipping cartons. When the cartons are removed from storage, the price, for example, may be imprinted on the end of each container by X or gamma irradiation through a shipping template. (MG)

*Abstract of U. S. Patent No. 3,560,745, by R. E. Petersen and J. W. Crowe, Feb. 2, 1971 (filed Apr. 26, 1966).

Study of Control of Some Public-Health Pathogens in Meat

By R. B. Maxcy, N. P. Tiwari, and C. C. Anagnostis*

(Summarized by F. E. McKinney)

Supplementary Keywords: *industry, food; microorganism.*

Abstract: *Ground meat products sold in retail stores were investigated to see if low levels of radiation could contribute to control of microorganisms of public-health significance. Commercial products commonly contain members of the family Enterobacteriaceae, which are sensitive to gamma radiation. Some of this contamination can be reduced by controlled central processing. Radiation can be applied after central processing and packaging to destroy a substantial portion of the contaminating microorganisms. This article is a summary of USAEC Report COO-2038-2, May 1971.*

Irradiation processing is a potentially ideal system for pasteurizing solid and semisolid foods. Treatment after packaging could destroy contaminants of public-health significance and prevent subsequent contamination during transportation and marketing, particularly if the product is processed at some central plant. Ground red meat—pork or beef—is a product of great interest for this application. It is accepted universally; it is broadly exposed to contamination; and it cannot be pasteurized by any current method—like many fresh products. Under a contract with the Division of Isotopes Development, USAEC, researchers at the University of Nebraska have investigated the application of low doses of radiation to ground red meats to control such microorganisms. Irradiation may not destroy all pathogens, but, by destroying a major portion, irradiation may reduce the likelihood of objectionable microorganisms and resulting hazards to public health. The literature dealing with the irradiation of meat and poultry has been reviewed by Urbain and coworkers.[1]

RADIATION SOURCE AND METHODS

A shipboard irradiator from the USAEC food irradiator support program[2] was used for this study. In November 1968, it contained 28 kCi of ^{60}Co. No temperature control during irradiation was possible, but samples were refrigerated before and after treatment. The ratio of maximum to minimum absorbed dose was always less than 1.25, and Fricke dosimetry was used to determine absorbed dose.[3] Samples were irradiated on both sides simultaneously in polyethylene pouches in the environment considered to prevail in industrial practice. The doses used were 68 and 34 krads.

Early work dealt with samples of ground beef and ground pork sausage from local supermarkets, but a source of centrally processed high-quality ground beef was used for the inoculation and storage studies. Standard methods were used for microbiological isolation, incubation, and identification. Both sample washes and plugs were used.

SURVEY OF LOCAL SUPERMARKETS

Results of a survey of ground beef in six local supermarkets are given in Table 1; data for ground pork sausage were similar. The least contaminated ground beef contained over 10^6 microorganisms per gram; the most contaminated contained 150 times that. All samples were judged spoiled to the point of consumer rejection after storage simulating a weekly

Table 1 Total Count and Coliform Count in Ground Beef from Local Supermarkets

Store	Count at the time of purchase		Count after 6 days at 5°C	
	Total/g	Coliform/g	Total/g	Coliform/g
1	1.5×10^8	4.1×10^5	6.9×10^9	6.0×10^7
2	4.7×10^6	2.6×10^4	8.1×10^9	2.6×10^8
3	4.1×10^7	1.6×10^5	1.1×10^8	9.2×10^5
4	8.7×10^6	8.5×10^3	1.9×10^9	6.6×10^6
5	3.7×10^6	9.0×10^3	5.8×10^9	2.2×10^7
6	4.5×10^6	1.9×10^5	1.5×10^9	1.2×10^8

*Department of Food Science and Technology, University of Nebraska, Lincoln. Original report title: Study of Control of Public Health Problems Using Irradiation, Annual Report, May 1, 1969–Apr. 30, 1970.

shopping routine and home storage (6 days at 5°C). Enterococci and coagulase-positive staphylococci were commonly found in both pork and beef; salmonellae were also found in pork.

Fresh ground beef from a commissary, which emphasized high-quality products for further distribution, showed much lower levels of contamination; initial total count averaged only 1.1×10^5 per gram. Samples were irradiated at 34 krads and at 68 krads; total microbial loads were reduced 84% and 97.5%, respectively. In fresh unirradiated samples, gram-positive asporogenous rods, micrococci, and pseudomonads constituted the major portion of the total microflora; most of the asporogenous gram-positive rods were catalase-negative, which implied that they were lactobacilli. After storage, there was an increase in the number of gram-negative rods and a decrease in micrococci. Irradiation eliminated nearly all the gram-negative rods.

MICROBIOLOGICAL OUTGROWTH

Comparative bacterial counts were made in irradiated and unirradiated ground beef after storage at 2 and 5°C. A count of 5×10^7 microorganisms per gram was taken as the criterion of spoilage. The unirradiated beef at 5°C contained 1.1×10^9 microorganisms per gram at the time (6 days) when the beef at 2°C reached the spoilage limit. Beef irradiated to 68 krads took 14 days to spoil when stored at 2°C and 8 days at 5°C.

Escherichia coli was taken as representative of coliform organisms, which are considered indicator organisms for a broad spectrum of contaminants. Outgrowth of *E. coli* was compared to that of *Salmonella typhimurium* to substantiate the idea that behavior of coliform organisms was similar to that of pathogens of popular concern. Beef was inoculated, irradiated, and stored at 5°C. In unirradiated samples, coliforms increased, but *S. typhimurium* did not. In irradiated samples, the coliform count decreased steadily during storage, and numbers of *S. typhimurium* decreased slowly.

Mishandling was simulated by storage of samples at 25°C. Unirradiated samples spoiled (1.7×10^7 microorganisms per gram and a distinct off-odor) in 11 hr. The *S. typhimurium* in irradiated samples showed a 4-hr lag before increasing rapidly; total plate count in the irradiated sample also showed a 4-hr lag. Results with *E. coli* were similar.

MICROORGANISMS SURVIVING IRRADIATION

Gram-negative cocci were found in irradiated products immediately after treatment and also after storage. This group of microorganisms is not generally recognized as a common contaminant of unirradiated products; their presence indicated a shift in the makeup of the microflora as a result of irradiation. Some of these microorganisms were very radiation resistant. The physiological and morphological characteristics of this group identified them as being in the loosely defined genera *Moraxella, Herrellea,* and/or *Mima.* Further work showed that these microorganisms were present in unirradiated samples. Apparently these relatively inert organisms have attracted very little attention because of the far larger number of other bacteria.

ATTENUATION FACTOR AND DOSIMETRY

In an evaluation of the destructive effect of radiation on microorganisms relative to their location in a piece of meat, known cultures were irradiated with and without the attenuating effect of 10.6 cm of ground beef. Time of exposure was adjusted so that comparable doses were given. The microbiological results showed that the destructive effects of the two exposure systems were equal.

LOCATION OF CONTAMINATION

Commercial ground beef is assembled from a variety of cuts and a variety of sources. If the contamination of the product is almost totally surface contamination, then good sanitation should be instrumental in providing an uncontaminated end product. Samples were investigated by washing, rewashing, and grinding. Microbial recovery was determined at each step in the sequence. Results indicate that, although surface growth is greater, growth occurs throughout the sample and there is no unique position or location for types of microorganisms. Study of plug samples from large cuts of red meat confirmed that the outer surfaces harbored most contamination.

AN INDICATOR OF VECTORS OF CONTAMINATION

Exploratory work on the use of *Serratia marcescens* as an indicator organism showed that the

organism can be used with surface plating on plate count agar; the primary criterion is to emphasize color differences from pigmentation by *S. marcescens.* The test is reliable, and *S. marcescens* should be useful as a tracer of vectors because its longevity and growth characteristics are fairly similar to those of coliform organisms.

CONCLUSIONS

The present system of in-store processing of red meats makes close control by regulatory sanitarians an almost insurmountable task. A sampling has indicated that ground beef as presently sold by supermarkets contains sufficient contaminating microorganisms to require the housewife to either freeze the meat or use it quickly. Because ground beef is cooked before it is used, the relatively high level of contamination has been excused in the past. This practice is no longer defensible, however, because of the recognized possibilities for cross-contamination to foods not intended for cooking. Many of the potential hazards could be overcome through the use of a central processing plant. Irradiation could be included as part of the processing, after the product is packaged. The results of this study indicate that a major reduction in occurrence of pathogens of public-health significance could thus be obtained. The magnitude of success will depend on radiation dose and other factors to be studied.

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Reference marked with an asterisk has not been verified by the editors; for further explanation, see the Foreword.

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NEW SYMBOL FOR PACKAGED IRRADIATED FOODS

In a paper presented at a conference on irradiation of potatoes held at Brussels, October 1969, R. M. Ulmann of the Dutch pilot plant at Wageningen announced that a symbol (Fig. 1) has been designed for use in the Netherlands to identify food products that have been irradiated. This symbol should become not only a recognition mark for irradiated products but also a product and process guarantee for the consumer. It may be used only if the wholesomeness of the irradiated product has been approved by appropriate health authorities. The new symbol may in time become internationally known and recognized. (FEM)

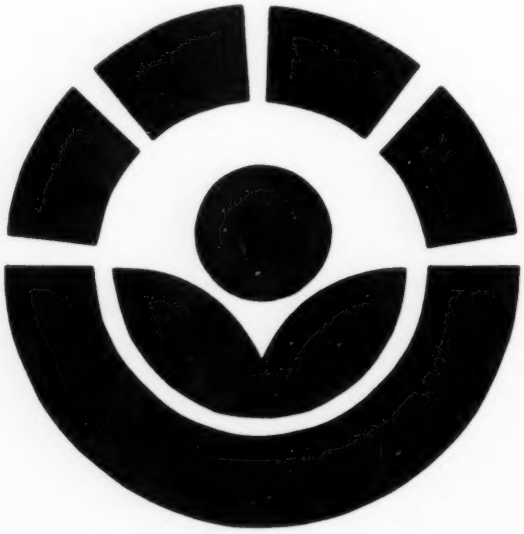

Fig. 1 Dutch symbol for irradiated foods.

Preservation of Fish by Irradiation

(Summarized by F. E. McKinney)

Supplementary Keywords: *seafood; food preservation; industry, food; conference.*

Abstract: *The proceedings of an IAEA conference on preservation of fish and other seafoods by irradiation, held in Vienna on Dec. 15–19, 1969, are summarized. Ten papers on different aspects of the problem were presented. More research was recommended in three areas—definition and maintenance of market life, standardization of working tools (i.e., dosimetry), and assessment and study of* Clostridium botulinum *contamination.*

On Dec. 15–19, 1969, the International Atomic Energy Agency (IAEA) sponsored a panel meeting[1] in Vienna on the use of radiation to preserve seafoods. The panel was made up of 13 members from nine countries, plus representatives from IAEA and the World Health Organization. The major problem in attaining a more complete exploitation of the abundant supply of protein-rich products of the sea is preserving them so that they can be transported to areas of greatest need. Detailed discussions were held on research in perfecting the radurization treatment of seafood, and evaluations were made of the microbiological changes brought about by the radurization process, with special reference to control of *Clostridium botulinum.*

RESEARCH

Ronsivalli and coworkers[2] (United States) reviewed studies carried out in support of petitions to the Food and Drug Administration (FDA) for approval of radiation pasteurization of fishery products. Information must be provided to the FDA on the proposed conditions of use, the accomplishment of intended effect with minimum possible dose, the analytical methods (i.e., dosimetry) used to determine the amount of radiation, and investigations into the wholesomeness of the final product, with full details given on methods and controls. The fact that irradiated fish do eventually spoil has been established.[3] A test was developed for evaluation of botulism hazards based on comparison of the time interval between spoilage and toxin production in inoculated and uninoculated irradiated and nonirradiated fillets. Spoilage is determined by measurement of maximum shelf life, referred to as the "X-value"; the criterion is unanimous rejection by a panel of 20 or more members. The mathematical tools of probit analysis and regression analysis were used to study the margin between X-value and toxin outbreak. In simulated commercial shipping studies, fillets were purchased on the open market, irradiated, and shipped via commercial carrier to points far outside the normal distribution area for fresh fish. All irradiated fish were of acceptable quality even after being flown back to the point of origin.

Laycock and Regier[4] (Canada) reported studies on the effect of radiation on microbial spoilage patterns, especially on fish that were several days out of the water before irradiation. In general, the pseudomonads are replaced as the principal component of microflora by the less active but more radiation-resistant achromobacters during aerobic refrigerated storage of irradiated fish. The state of the fish muscle has an effect on storage life because most fish receive exposure to contamination and initial microbial load at the time of filleting, and the time between catch and gutting affects the response of the fish muscle to this exposure. In this experiment, iced fish that were 2, 5, and 9 days out of the water were filleted, irradiated, stored, and evaluated. The unirradiated 2-day fish had a shelf life of 9 days at 3°C; the irradiated fish were acceptable up to 18 days. Similar figures for 5-day fish were 7 days and 18 days and for 9-day fish, 5 days and 13 days. The quality of unirradiated fish declined rapidly immediately before becoming unacceptable, but the quality of irradiated fish declined slowly and remained borderline for long periods before finally becoming unacceptable. Quantitative analysis showed initial contamination was 10^5 microorganisms per gram on 2- and 5-day fish and 10^6 on 9-day fish. Unirradiated fish were judged to be spoiled when total plate counts reached about 10^7 to 10^8 microorganisms per gram, but irradiated fish were not judged to be spoiled until contamination reached 10^9 per gram. This difference is thought to be caused by the lower metabolic activity of surviving microflora, i.e., greater numbers are required to produce an equivalent amount of spoilage. Initial quality of unirradiated fillets did not seem to affect the kinds of organisms developed during spoilage—pseudomonads predominated. Similarly, achromobacters were the chief isolate from irradiated fillets, regardless of age. *Pseudomonas putrefaciens* was the only microorganism

capable of producing trimethylamine from trimethylamine oxide during storage, providing a link between spoilage and trimethylamine production.

Sierra Serrano[5] (Spain) described experiments on prolonging the commercial life of hake (*Merluccius merluccius*). Doses from 50 to 300 krads were used; packaging material, temperature, and atmosphere were varied. Preliminary tests on whiting showed that a 300-krad dose would delay decomposition for 21 days, although some organoleptic changes were detected. Four experiments were carried out in which temperature was varied, dose was varied, vacuum and normal atmosphere packaging were compared, and combinations were tried. The conclusion reached was that 50- and 100-krad doses are adequate for prolonging storage life by 12 to 18 days when fish are stored in impermeable plastic at 3°C.

The results of a survey project in Iceland on the use of radiation to preserve various seafoods were presented by Hannesson and Dagbjartsson.[6] Iceland's domestic fish market is very limited, and most of the catch is salted, dried, or frozen and then exported. Iced fish are shipped to Europe, but an extension in shelf life of this product would expand markets and be of great economic benefit. Products studied were cod, Norway lobster, and deep-sea shrimp. The lobster tails were irradiated in metal cans; the cod and shrimp were irradiated in polyethylene bags. Black color formation (melanosis) in lobster tails was worse in irradiated specimens but could be controlled by blanching the tails before irradiation. Storage at 1°C was twice as long as that at 6°C. Untreated tails were unacceptable after 6 days; tails irradiated at 200 krads had a storage life of up to 3 weeks; blanched tails were good for 4 weeks; blanched and irradiated samples had a storage life of 5 to 6 weeks. However, since the relatively low figure of 10^6 bacteria per gram was set as the upper limit of acceptability, actual shelf life may be even longer. The blanching treatment was also used with the preservation studies on deep-sea shrimp. Results of using a taste panel, a set limit for total bacterial count, and a set limit of trimethylamine production for judging the end of acceptability were compared. Taste-panel results agreed fairly closely with total bacterial-count results, but trimethylamine production appeared to be unreliable as a terminal index of blanched irradiated shrimp. The optimum dose for peeled shrimp is below 200 krads; undesirable organoleptic changes occurred at this dose. The optimum treatment of 5-min blanching and 100-krad irradiation of peeled shrimp gave a shelf life at 1°C of 6 to 7 weeks. Experiments with cod caught by line, by gillnetting, and by trawling were extensive. Line fisheries consistently gave the best quality cod; trawl fisheries were variable and net fisheries were lowest in quality. Trimethylamine production as an index to quality was more in agreement with total bacterial count and organoleptic tests in this experiment. A 300-krad dose caused undesirable changes in cod fillets. Also investigated was a preliminary dose of 50 krads to whole cod followed by a dose of 150 krads after cod were filleted. The longer whole cod were stored, the shorter the storage time of the fillets was—even after the second dose of radiation.

Ehlermann and Münzner[7] (West Germany) gave results of studies on radiation preservation of freshwater fish. Gwyniad,* carp, and trout were vacuum-packed in impermeable plastic-lined foil, irradiated with 10-MeV electrons, and stored on ice. Carp and trout are raised on fish farms and are frequently transported live in large tanks. The improvement in shelf life effected by irradiation would make the large tanks unnecessary and would enable gwyniad to be transported farther. For both gwyniad and trout, undesirable organoleptic changes occurred at doses greater than 100 krads, but some taste-panel members particularly liked the taste of carp given high doses of radiation. No softening of flesh due to irradiation was observed, although long storage led to softening, particularly in carp. A dose of 500 krads was considered optimum for carp; shelf life was 35 days. For gwyniad, 100 krads gave a shelf life of 22 days instead of the usual 8 days. An extension of shelf life from 15 to 26 days for trout was obtained with a 50-krad dose. There was a discrepancy between sensory and chemical tests for spoilage of gwyniad, but agreement on carp and trout.

Kumta and Sreenivasan[8] (India) reported work on Bombay duck, shrimp, and white pomfrets. Bombay duck constitutes almost 10% of India's total catch of fish and is usually preserved by sun drying; it has a high free-water content and cannot be canned or frozen. After irradiation, chromogenic *Micrococci* were the major survivors; further storage led to development of nonchromogenic *Micrococci* and *Achromobacter*. A dose of 100 krads extended the shelf life of Bombay duck to 17 to 19 days at 1°C without increasing drip loss, which was also cut by dipping the fish in a 10% NaCl solution for 60 min before irradiation. Other preservation methods were tried in conjunction with irradiation. Pressing out free water between wood

*A kind of lake whitefish that is a specialty around Lake Constance. *The Editor*

plates before irradiation at 250 krads brought about a 3-week extension in shelf life at 0°C. Reducing water content to 40% before irradiation enabled the product (referred to as a laminate) to be stored at room temperature. Further air drying to a 5 to 10% water content reduced the radiation requirement to a disinfestation level of 25 krads; this dried Bombay duck can be stored in polyethylene bags for over a year. Shrimp used in these studies were the large-size, export-quality prawns. Extension of shelf life of deveined, peeled shrimp exposed to 150 krads and stored at 0 to 2°C was 18 to 20 days; higher doses caused color bleaching. Melanosis could be controlled by blanching in combination with radiation; blanching alone was not sufficient. Precooking plus irradiation to 150 krads led to storage at room temperature; this process is still being tested for possible botulism hazards. Low-dose irradiation after partial dehydration allowed the product to be preserved for up to 35 days at room temperature. White pomfrets have not been processed by conventional methods of canning or drying, although some have been quick frozen, which leads to a yellow discoloration. The skin of the pomfret is very sensitive to radiation, but packaging minimized the effect. Organoleptic change in air-packed pomfret was detectable after 500 krads; no organoleptic change was detectable in vacuum-packed pomfret after irradiation up to 1500 krads. No oxidative yellowing was noted in vacuum-packed irradiated samples, which lasted 35 to 40 days at 0 to 2°C. The air-packed irradiated samples (100 krads) spoiled after 25 days. Studies of the transportation of irradiated Bombay duck, eel, and shrimp in iced containers via train have demonstrated the feasibility of developing inland markets for seafoods.

Matutano Aranda and Rodriguez[9] (Spain) irradiated hake fillets in plastic bags at doses of 100, 150, and 200 krads. Hake is an economically important fish for Spain; the catch in 1968 was over 73 thousand tons. The bags tested were oxygen-permeable polyethylene and an oxygen-impermeable French nylon (Rilsan*); both materials were sterilized before use by irradiation. Biochemical indexes as well as test panels were used to assess the results of the irradiation treatments. The biochemical tests indicated that the nonirradiated samples spoiled in the first week, 100-krad samples in the third week, and 150- and 200-krad samples in the fourth week. This agreed fairly well with sensory evaluation of raw samples—controls were rejected in the second week, 100-krad samples in the fourth week, 150-krad samples after the fourth week, and 200-krad samples in the fourth week. Rejection of the 200-krad samples may have been due to radiation-induced changes rather than spoilage. Results with cooked fish were similar. The packaging tests showed that Rilsan gave better results than polyethylene; both controls and irradiated samples lasted longer after irradiation when vacuum packaged. These researchers concluded that a 100-krad dose gave sufficient shelf-life extension; however, vacuum packaging and use of Rilsan did not offer any advantages at this low dose.

The possibility of a botulism hazard in irradiated fishery products was evaluated by Shewan and Hobbs[10] (United Kingdom). A feasibility study[11] has shown that the most likely application of irradiation will be to fillets packed to a standard weight in flexible material at a central plant for distribution through standard retail outlets equipped with refrigerated holding cabinets. Only good quality fish will be marketed; the entire shelf life will not be used. Despite this, packaged iced fish is still likely to be the most perishable item in the store. The housewife is instructed now to consume fish either on the day of purchase or the very next day; this pattern would be retained even with irradiated fillets. The incidence of *Clostridium botulinum* in the United Kingdom is relatively small—5 out of 600 samples in retail stores in one instance, 15 out of 429 bottom deposit samples in another—but must be considered in evaluating the safety of radiation-pasteurized seafoods. Standard practice requires that the temperature never exceed 3°C during processing, packaging, distribution, storage, and display of fish because the minimum temperature for the growth of *C. botulinum* is about 3.8°C. Processing of smoked fish and breaded products raises the temperature above this limit; however, neither process provides suitable conditions for development of significant amounts of toxin. Further, cooking 5 min at 65°C will destroy Type E toxin. Kipper fillets and smoked salmon are eaten without further processing, however, and there are potential botulism hazards if the products are mishandled at any point before consumption. Irradiation does seem to increase the hazard in some fish, such as herring, that have a high glucose and ribose content and are known to be more botulinogenic than other species. For this reason, irradiation at doses of 100 krads, which would not kill off all competitive bacteria, would seem to be preferable to higher doses.

Eklund and Poysky[12] (United States) reported results of studies into the significance of nonproteo-

*Registered trademark of Aquitaine Chemicals Inc.

lytic *C. botulinum* Types B, E, and F in the development of radiation-pasteurized fish. Inoculated pack studies were carried out with haddock, cod, and three kinds of sole at irradiation doses of 100 and 200 krads and storage temperatures between 38 and 50°F (3.3 to 10°C). Data so far indicate that there is no additional health hazard if the temperature is held below 42°F (5.6°C). The 100-krad product was judged safe at 46°F (7.8°C), but the 200-krad product had what was judged to be an insufficient safety margin in heavily inoculated samples. At 50°F (10°C), no product—irradiated or not—had any safety margin between maximum storage and toxin development. All three kinds of sole—petrale, English, and Dover—were better substrates for *C. botulinum* than haddock or cod. Toxin developed in irradiated sole stored at 42°F (5.6°C) in vacuum-packed impermeable plastic bags; it did not develop in oxygen-permeable-packaged sole. Further study of nonproteolytic *C. botulinum* Types B and F is under way, along with research into the relationship of bacteriophages of *C. botulinum* to the toxigenicity of the bacterium.

The importance of dosimetry being uniform and universal was stressed by Leone[13] (United States). Inconsistency in results occurs not infrequently in radiation-pasteurization studies, and many factors have been suggested to explain this (differences in maturity, freshness, native harvest conditions, climate, etc.). Another major factor, however, is uniformity of dose. Before the results of an experiment can be properly interpreted, the absolute maximum and minimum absorbed radiation doses must be known, and there is always a gradient of absorption from the outside to the inside of the target (i.e., food product) which must be known and understood. Some experimenters fail to acquire and report this very necessary information. The more uniform the dose for any radiation treatment, the more uniform will be the results. Uniformity ratios close to 1.0 can be attained if the researcher has knowledge of dose distribution in his target. After-the-fact dosimetry studies have had to be conducted to salvage data from costly biological studies, and the inoculated pack research in the United States is being reviewed so that a more accurate interpretation of past data will result. Adequate and uniform dosimetry practices are an absolutely essential part of all experiments concerning the irradiation of food products.

CONCLUSIONS

The meeting was convened to review research and discuss problems in three specific areas: market-life extension, standardization of working tools, and evaluation of *C. botulinum* as a possible hazard in irradiated fishery products. An extension of market life is needed, primarily to elevate the nutritional and economic status of populations in various countries. There is little standardization of measurement or expression of dose or product quality at present. The presence of *C. botulinum* must be assumed in all fishery products, but, if all processing and handling is carried out below 3°C, shelf life can be increased by a factor of 3 with no increase in hazard. At higher temperatures, increased shelf life can lead to an increase in botulism hazard. Some products are better substrates for growth and toxin production of *C. botulinum* than others.

RECOMMENDATIONS

Only fishery products of good quality should be irradiated to prolong their market life. Strict control of temperature must be maintained in the handling and storage of irradiated fishery products; the development of a visual temperature indicator for packages of products is strongly urged. The effect of packaging material on shelf life must be investigated, and more research is needed to find satisfactory chemical indexes of food quality.

The dose distribution in each product for each target geometry must be measured to determine the absolute maximum and minimum absorbed doses. Data must be expressed in a statistically satisfactory way, and the dosimetry method and calibration process must be given in detail. Continued research is needed to find more practical and convenient dosimeters for food irradiation. Standardization of sensory assessment methods is not practicable, but sufficient details of the method should always be given to enable satisfactory statistical treatment and correlation with other test methods.

Large-scale radurization experiments should be carried out with fish known to be naturally contaminated with *C. botulinum* to assess the actual extent of the botulism hazard. More inoculated pack studies are needed to determine precisely the conditions under which toxin is produced. Existing methods must be improved and new methods derived for determining degree of contamination of fishery products with *C. botulinum*; these methods must use standardized microbiological procedures and sampling plans. The incidence of *C. botulinum* in conventional fish processing plants must be established, and the factors

leading to development and accumulations of *C. botulinum* must be studied.

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Radiation Pasteurization of Pacific Coast Fishery Products

By D. Miyauchi*

(Summarized by F. E. McKinney)

Supplementary Keywords: *food preservation; industry, food; seafood; food evaluation, subjective; biochemistry.*

Abstract: *This article summarizes 8 years of research on the use of radiation to preserve different types of Pacific coast fishery products, primarily finfish. Optimum dose is 100 to 200 krads. Studies of shipping between Gloucester, Mass., and Seattle, Wash., proved feasibility of use of low dose to preserve fish. Taste panels showed that there was no significant difference in consumer preference. Studies of microbial growth differences and products between irradiated and nonirradiated fish were carried out. This article is a summary of USAEC Report TID-25546.*

From October 1961 through October 1969, researchers at the National Marine Fisheries Service (formerly Bureau of Commercial Fisheries) Laboratory in Seattle, Wash., under contract to the USAEC Division of Isotopes Development, investigated the application of low doses of radiation to many seafoods. In this article, the findings of those 8 years of research[1-8] are summarized. The minimum dose of radiation that will extend the refrigerated storage life sufficiently to allow economical nationwide distribution of a high-quality product should be used[9] so that (1) the product differs little from the original fresh fish, (2) storage life will be terminated by bacterial spoilage rather than other degradation causes, and (3) the cost of irradiation is kept as low as possible. Pacific Ocean finfish (petrale sole, English sole, Pacific ocean perch, cod, and halibut) were emphasized, but crab and oysters were included because enough products are needed to enable any irradiation facility to operate economically year-round, i.e., to avoid seasonal fluctuations in production.

*Technology Laboratory, National Marine Fisheries Service, Seattle, Wash. Original report: Application of Radiation-Pasteurization Processes to Pacific Coast Fishery Products, Final Summary Report, October 1961–October 1969.

STORAGE-LIFE STUDIES

Retail Packaging

Packaging in oxygen-impermeable material and eliminating air from the package gave best results for halibut steaks,[4] fillets of petrale sole,[10] English sole,[4] Pacific ocean perch,[5] and cod.[6] Air left in the package caused discoloration of fatty tissue and development of off-odors and flavors after 1 to 2 weeks at 33°F. For Dungeness and king crab meats,[11,12] cans or heat-sealed polyester pouches were suitable; for oysters,[6] jars with screw-cap lids and cans were used. A dose of 100 to 200 krads was sufficient to give a shelf life of 2 to 5 weeks at 33°F—two to five times that of nonirradiated products (Table 1).

Table 1 Shelf Life of Irradiated and Nonirradiated Pacific Ocean Fishery Products (Seattle Laboratory)

Product	Dose, krads	Shelf life, days	
		33°F	42°F
Petrale sole fillets	None	4–11	3–7
	100–150	20–25	3–8
	200	21–42	12–18
English sole fillets	None	4–6	
	100	14–21	
	200	21–28	
Pacific ocean perch fillets	None	6–7	
	150–200	25–28	
Pacific cod fillets	None	5–7	
	50	8–9	
	100	15–18	
	200	19–22	
Halibut steaks	None	4–18	4–8
	100	14–21	
	200	21–56	14–21
Dungeness crab meat	None	6–14	2–9
	100	14–35	14–21
	200	21–56	21
King crab meat	None	5–14	3–7
	100	21	7–14
	200	28–42	14
Pacific oysters	None	20	9
	100	30	11
	200	30–34	20–25

Wholesale Packaging

For wholesale distribution, 25 lb of fresh fish fillets are packaged in polyethylene bags; the shelf life is only 4 to 7 days. Extension of shelf life by irradiation would enable the processor to ship fish into more distant marketing areas. Experiments[5] indicated that English sole fillets packed in polyethylene or polyester bags and irradiated at 200 krads could be held 2 weeks at 33°F and then repackaged in retail form and held an additional 5 days. Results with Pacific ocean perch were similar.[6] Halibut responded best to storage in vacuum-packed cans,[6] as did Dungeness crab, which could be held as long as 20 days before being repackaged.[6,13]

SHIPPING STUDIES

Distributors and Retailers

Nearly a ton of irradiated Dungeness crab meat and fillets of petrale sole, Pacific ocean perch, and cod were shipped on ice, under control of laboratory personnel, to nine distributors and retailers in different cities in the western United States.[6] The shipments were made to evaluate packaging materials and containers, to determine the effect of commercial shipping on quality, to obtain industry evaluation of marketability of irradiated seafoods, and to obtain data to support petitions to the Food and Drug Administration for commercialization of irradiated flounder species.

The most suitable materials for shipping and storing were found to be water-resistant paperboard cartons containing oxygen-impermeable plastic bag liners, or 12- or 25-lb fillet tins. Temperatures were monitored continuously on all shipments; data indicated that good commercial handling practices were followed by all distributors. Fillets irradiated to 100 krads had a shelf life of at least 14 days; bacterial counts ranged from 10^4 to 10^6 per gram after 14 days of iced storage. Fillets irradiated to 200 krads gave the same shelf life, with bacterial count ranging from 10^3 to 10^5 per gram. Most industry personnel felt that radiation pasteurization would be of significant benefit to their operations.

Cooperating Laboratory

The laboratory at Gloucester* shipped by train to Seattle about a ton of fillets of Atlantic cod, haddock, and yellowtail flounder that had been irradiated to 0, 100, and 200 krads. Upon arrival, the nonirradiated fillets were in unmarketable condition; the irradiated

*National Marine Fisheries Service, Technology Laboratory, Gloucester, Mass.

fillets were in good condition and still marketable 1 to 2 weeks later.

In another experiment, English sole fillets, irradiated to 0, 100, and 200 krads, were shipped by truck from Seattle to Gloucester. The irradiated fillets had a 10-day longer shelf life.

PREFERENCE TESTS

Proof of technical feasibility and permission to commercialize radiation-pasteurized seafood will be futile if the consumer does not accept the products. Preference tests have been conducted with laboratory personnel to obtain data that would indicate probable acceptance of the product.[3,4,14] Petrale sole fillets, halibut, and Dungeness and king crab meats were either frozen and stored at −20°F or irradiated to 200 or 250 krads and stored at 33°F. The results indicated that no difference in preference scores was found between frozen control samples and irradiated refrigerated samples. Tests with Army personnel at Fort Lee, Va., indicated that irradiated petrale sole fillets were as acceptable as frozen control samples after 28 days' storage.[3]

PROCESSING VARIABLES

Package Atmosphere

Haddock, shrimp, and Dungeness and king crab were not affected by air in the package, but sole and flounder became rancid after 10 to 14 days of storage unless vacuum packaging was used. The formation of ozone in air during irradiation was thought to cause the rancidity, and addition of small amounts of ozone to packages of nonirradiated sole fillets caused severe rancidity in less than 3 days. Fish fillets were irradiated in atmospheres of nitrogen, carbon dioxide, and helium.[4,15] Only helium gave results comparable to vacuum packaging; radiolytic products from nitrogen and carbon dioxide led to flavor deterioration.

Effect of Storage Conditions on Microflora

The spoilage microflora of petrale sole fillets vacuum-packed in cans was predominantly *Lactobacillus,*[16] but fillets stored in oxygen-permeable films were spoiled by *Achromobacter* and *Trichosporon* yeasts.[17] Nonirradiated fish stored in either packaging spoiled predominantly by *Pseudomonas.* Yeasts in irradiated king and Dungeness crab meat[18,19] multiplied in samples packed in air but were almost completely suppressed in vacuum-packed samples.

Storage temperature is a critical factor in control of microbial populations. A study[20] made to determine the effect of temperature on microflora composition and on outgrowth of potential health hazard microorganisms (fecal coliforms, coagulase-positive *Staphylococcus aureus,* and enterococci) showed that irradiation suppressed the growth of most of these organisms. No *S. aureus* and very few enterococci were found, although coliform organisms did grow in nonirradiated fish stored at 42°F.

Sodium Tripolyphosphate Treatment

Changes occurring in storage that are not associated with microbiological growth include drip loss, flavor loss, color alteration, and texture alteration. The degree of change depends on storage time and temperature and varies with fish species. Treatment with a solution of 7.5% sodium tripolyphosphate and 2% NaCl minimized drip[21] and helped retain original appearance and texture, especially for halibut and Pacific ocean perch.

MICROBIAL SPOILAGE OF IRRADIATED FISH

Irradiating fish to low doses preserves fish because the radiation destroys or inactivates nearly all the microorganisms that are the main cause of spoilage. Significant quantitative differences in bacterial populations at the time of spoilage were found between irradiated and nonirradiated king crab meats.[22] Nonirradiated samples were judged to be unacceptable when the bacterial count exceeded 10^6 per gram, while irradiated samples were not considered spoiled until the count approached 10^8 per gram. There was also a qualitative difference in microflora between irradiated and nonirradiated seafood; differences in microflora are responsible for differences in odor.

Studies showed that *Trichosporon* yeasts, the predominant spoilage organisms in air-packed irradiated crab and fillets, produced lipolytic and proteolytic enzymes.[19,23] *Pseudomonas,* the spoilage organisms that predominate in nonirradiated fish, produced hydrolytic enzymes that caused malodorous breakdown products. *Lactobacillus,* which spoil vacuum-packed irradiated fish, were acid producers but produced no proteolytic or lipolytic enzymes.[3] Sensory and chemical analyses showed that *Pseudomonas* spoilage was characterized by putrefactive and ammoniacal odors, *Achromobacter* by sweet or watermelonlike odors that became nauseous, *Lactobacillus* by stale and sour odors, and *Trichosporon* by yeasty odors.[5]

ASSESSMENT OF QUALITY

Changes in fillets irradiated to 200 krads and stored at 33°F were rapid in the early and terminal phases of storage. Early changes could be correlated with degradation of inosine monophosphate and accumulation of hypoxanthine.[24-26] Flavor and odor were rather stable until bacterial counts approached 10^7 per gram. In the terminal phase, bacterial counts approached 10^8 per gram, volatile acid number exceeded 20, and about 75% of the free glucose originally present in the tissue had been consumed. Total bacterial counts, volatile acid numbers, nucleotides, hypoxanthine, and extractable myofibrillar protein in fish showed good correlation with sensory changes.[27] Trimethylamine production did not correlate with sensory changes in fish irradiated to doses above 150 krads.

IRRADIATION OF FISH AT SEA

The benefits of irradiating fish at sea before there are significant changes in quality and while the number of spoilage bacteria is lowest[7,28] were studied by irradiating Pacific ocean perch, black rockfish, cod, English sole, and Dover sole on board the research vessel *Miller Freeman* as the fish were caught off the Pacific Northwest coast. The optimum dose was 50 to 100 krads. Fish irradiated in either the prerigor or rigor states had better storage characteristics than fish irradiated after rigor; this follows since the prerigor state occurs 0 to 3 hr after catch, rigor 6 to 24 hr after, and postrigor 2 to 8 days after catch. Black rockfish could be held 2 days at 33°F and ocean perch and Dover sole for 5 days before irradiation and still have better storage characteristics than nonirradiated fish. Fish irradiated at sea and stored whole (after gutting) should be processed within 2 weeks; during longer storage periods, autolysis and discoloration occur. English sole and cod fillets cut from fish irradiated at sea to 50 krads and stored for 14 days before filleting had an additional shelf life of 4 and 7 days, respectively, over nonirradiated fish.

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Irradiation Preservation of Mushrooms

By P. Markakis, R. C. Nicholas, G. Blair, and N. Diaz-Santiago*

(Summarized by F. E. McKinney)

Supplementary Keywords; *food preservation; industry, food; vegetable; source, gamma; accelerator; comparison; food evaluation, subjective;* ^{60}Co.

Abstract: *A taste panel was unable to detect any significant differences, for 7 days after irradiation, between nonirradiated mushrooms and mushrooms irradiated at doses up to 100 krads. A comparison between gamma radiation from* ^{60}Co *and electrons from an accelerator showed clearly that gamma radiation was superior for inhibition of cap opening of mushrooms. A test of storage temperatures demonstrated that mushrooms remained closed for 3 weeks at 0.5°C whether irradiated or not, but, at 5°C, nonirradiated mushrooms opened three times as fast as mushrooms irradiated at 50 or 100 krads. Mushrooms were intentionally bruised in a study to determine the effect of radiation on this problem. Irradiated mushrooms remained lighter in color 6 days after bruising. Further study showed that irradiation at 50 krads had no effect on the enzyme responsible for browning of fresh mushrooms. Increasing* CO_2 *content of storage atmosphere had little effect on shelf life. Pennsylvania-grown mushrooms responded similarly to Michigan-grown mushrooms in these experiments. This article is a summary of USAEC Report COO-1592-36, for the period Apr. 16, 1968–July 15, 1970.*

Under a contract with the USAEC Division of Isotopes Development, the Department of Food Science, Michigan State University, has been studying the use of radiation to prolong the shelf life of fresh fruits and vegetables. One of the most promising products has been mushrooms. A low dose of radiation delays the opening of the cap and thus provides additional shelf life. The Netherlands has already approved and marketed irradiated mushrooms. Research in the United States has established the technical feasibility of the method; however, there are no plans at this time to petition FDA for clearance.

TASTE-PANEL EVALUATION OF IRRADIATED MUSHROOMS

Mushrooms were harvested in the morning and irradiated that afternoon in the ^{60}Co gamma source at

*Department of Food Science and Human Nutrition, Michigan State University, East Lansing, Mich. Original report title: Irradiation of Fruits and Vegetables.

Michigan State University. Doses were 12.5, 25, 50, and 100 krads. The mushrooms were evaluated by panels immediately after irradiation, 2 days later, and 7 days after the irradiation. Mushrooms were sliced, sautéed, and presented to the judges. Statistical analysis showed that there were no significant differences between samples; irradiation did not affect the taste of mushrooms.

PENNSYLVANIA MUSHROOMS

Pennsylvania mushrooms were obtained and tested to see if their response was the same as that of Michigan mushrooms. Doses given on the same day as harvest were 12.5, 25, 50, 100, and 200 krads. After irradiation, mushrooms were stored at 2°C.

Cap Opening

After 5 days, mushrooms were transferred to an 8°C environment to accelerate cap opening. Degree of opening was measured after 7 and 15 days from harvest. Opening ratio was determined at the end of the experiment by use of a destructive test. Data indicate that irradiation strongly retards cap opening of Pennsylvania-grown mushrooms, just as it does for Michigan-grown mushrooms.

Weight Loss

Measurements made 5, 7, and 12 days after irradiation indicated that for doses of 25 to 100 krads there may be a slight weight loss in irradiated mushrooms.

Color Evaluation

Visual observation 7 days after irradiation showed that irradiated mushrooms were lighter in color than nonirradiated mushrooms by a statistically significant amount. The color of the 100-krad lot was between that of the other doses and the controls.

COMPARISON OF ELECTRONS AND GAMMA RAYS

A comparison of the effects of electrons vs. gamma rays was undertaken using an electron accelerator and the ^{60}Co source. The mushrooms receiving electron irradiation were divided into two groups—one group was irradiated stem up and one group stem down. Doses used were 12.5, 25, 50, 100, and 200 krads. After irradiation, mushrooms were stored 4 days at 10°C and 90% relative humidity. Measurements of weight loss, degree of opening, and opening ratio were then made. No definite trend in weight loss was evident, but gamma radiation was clearly superior in inhibiting cap opening. Also, the stem-up position gave better results than the stem-down position for electron irradiation because of the shielding action of the mushroom cap.

BRUISING OF MUSHROOMS

Two experiments were set up to examine the effect of radiation on bruising of mushrooms. Mushrooms are very susceptible to this injury, which causes darkening of the tissues.

For the first experiment, mushrooms were left unbruised or were bruised by dropping them, stem up, 50 cm to a hardwood table. Doses were 25 or 100 krads, and mushrooms were bruised either before or after irradiation. Storage was at 10°C for 3 or 6 days. Statistical analysis showed that irradiation was able to reduce the discoloration of bruising, especially after 6 days' storage. There was no apparent difference in effectiveness between the two doses, nor did it matter whether mushrooms were irradiated before or after bruising.

In the second experiment, bruising was caused by a mechanical shaker. Other treatments were the same as in the first experiment. Statistical analysis of visual judgments confirmed that, even if bruised, irradiated mushrooms will remain lighter than unbruised nonirradiated mushrooms.

STORAGE-TEMPERATURE EFFECT

Extrapolation of data from storage experiments conducted at 5, 10, or 15°C indicated that there should be little cap opening in mushrooms stored at 0°C. This conclusion was tested by storing mushrooms (nonirradiated or irradiated to 25, 50, or 100 krads) at 0.5 and 5°C. Mushrooms at the higher temperature were evaluated after 7, 14, and 21 days of storage for transpiration rate, degree of opening, and opening ratio. Mushrooms at the lower temperature were tested after 5, 10, 15, and 20 days of storage.

At 5°C, nonirradiated mushrooms lasted only 6 to 7 days before exceeding the suggested but arbitrary opening-ratio limit of 0.8; irradiated mushrooms were still below the limit after 20 days. Mushrooms stored at 0.5°C remained below the limit whether irradiated or

not. Transpiration rate differences between irradiated and control mushrooms were insignificant, and no off-odors were detected.

EFFECT OF RADIATION ON PHENOLOXIDASE ACTIVITY

Phenoloxidase is the enzyme responsible for the browning of fresh mushrooms; because irradiation decreases darkening, radiation was thought to have some effect on this enzyme, although such low doses would not usually be expected to affect enzymes in situ. In an experiment to test this idea, mushrooms were irradiated on the day of harvest to doses of 10, 50, 100, and 1000 krads. The crude enzyme was then extracted; about 2 g of dried-extracted powders were obtained from each 25 g of mushrooms. After 3 days at 4°C, the activity of the enzymes was tested spectrophotometrically. The data showed little if any effect of radiation and failed to explain the diminished darkening of mushrooms exposed to radiation up to 100 krads.

CONTROLLED-ATMOSPHERE STORAGE OF MUSHROOMS

Mushrooms were irradiated to 50 krads and stored at 11°C in containers swept with an atmosphere of air or air with 5% CO_2, a common controlled-storage atmosphere for fruits and vegetables. Degree of opening and opening ratio were measured on day of irradiation and after 5 days of storage. Data were analyzed statistically; inhibition of cap opening was clearly a function of radiation—increased level of CO_2 gave no detectable effect.

CONCLUSIONS

Doses up to 100 krads do not statistically affect the taste of mushrooms. Pennsylvania mushrooms respond to radiation similarly to Michigan mushrooms. Gamma radiation is superior to electron bombardment as a means of inhibiting cap opening. Irradiation not only inhibits cap opening, it also serves to reduce bruise damage. Studies undertaken to investigate the interaction of radiation and enzyme activity were unsuccessful.

CORRECTION

In the table on pages 186 and 187 of Vol. 9, No. 2, of this journal, the permissible doses should be expressed in *kilorads* instead of *rads*.

Section
III
Isotopes and Radiation Technology

Process Radiation Development

Polymer Grafting to Inorganic Substrates

By R. A. V. Raff, R. V. Subramanian, D. J. Schecter, and M. F. Adams*

(Summarized by R. E. Greene)

Supplementary Keywords: *polymerization; industry, plastics; industry, stone, clay, and glass; source, gamma; physical property.*

Abstract: *In further work by Washington State University on polymer grafting to inorganic substrates, the results of a study of the effects of gamma radiation on a few polymer–filler composites and two metal–epoxy-resin systems are briefly described. This article is a summary of USAEC Report RLO-2098-2, annual report for Feb. 1, 1970–Jan. 31, 1971.*

Washington State University, under contract to the Division of Isotopes Development, USAEC, has been studying the grafting of organic polymers onto inorganic substrates. In earlier work,[1] a critical study of the literature provided ample evidence that unusual properties may be expected in combinations of organic polymers with inorganic materials and that high-energy radiation is a suitable source for promoting these mixed graft reactions. Subsequent work involved laboratory studies[2-4] using radiation for the preparation of active fillers for resins, pretreatment of glass fibers used in reinforcing resins, preparation of temperature-resistant and/or high-strength mixed grafts, and preparation of ion-exchange resins grafted onto porous ceramics. On the basis of the findings of this work, investigations of the effects of gamma radiation on a few polymer–filler composites and two metal–epoxy-resin systems were made in greater detail; these are summarized here. The ^{60}Co irradiator has been described previously.[2]

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POLYMER COMPOSITES

The properties of gamma-irradiated polymer composites—polystyrene, polysulfone, and both high- and low-density polyethylenes—were studied. On most samples the inorganic fillers were carbon black and aluminum oxide, but limited testing was done with calcium carbonate, sodium aluminosilicate, silica gel, silica, and magnesium oxide fillers. Short ($\frac{1}{64}$ in.) and long ($\frac{1}{2}$ in.) glass fibers were also used in laboratory-prepared blends or in commercial glass-fiber-reinforced polyethylene and polysulfone.

The combined effect of reinforcement and gamma irradiation on mechanical properties in general, and on the creep behavior in particular, was examined by irradiating, in an inert atmosphere, test specimens molded from the polymer–powder or polymer–fiber blends. A master-batch technique was also tried with carbon-black and aluminum oxide fillers. In this technique polymer highly loaded with filler was molded, irradiated, broken up, and then blended with unirradiated polymer for molding into test specimens with the desired ratio of filler to resin. This method has the advantages that less material need be irradiated and that master batches can be used commercially as an "activated" filler, without any source of radiation. Irradiations were done in an inert atmosphere to prevent oxidative degradation of the polymers. Radiation doses were held in the range 10^7 to 10^8 rads, which was chosen[5] as optimum for the promotion of radiation-induced polymer reactions, especially grafting, while keeping radiation damage at a minimum. Tensile and flexural strengths and moduluses, in some

cases, compressive strengths and moduluses, and Rockwell hardness were determined. Under static stresses, flexural-creep measurements were made.

With polyethylene blends, mechanical properties were considerably improved by gamma irradiation. Long-term flexural-creep measurements showed that creep resistance of the irradiated specimens had also increased. Gamma irradiation in the dose range 10^7 to 10^8 rads caused no enhancements, only deterioration in the strengths of specimens made from polystyrene, polystyrene–carbon-black blends, polysulfone, or polysulfone–glass-fiber blends. An interpretation of the observed improvements in physical and mechanical properties of filled and unfilled polyethylene is presented in the full report; at least three chemical reactions—degradation, cross-linking, and polymer grafting to filler—are considered.

METAL–EPOXY-RESIN SYSTEM

The effect of gamma irradiation on the adhesion of copper and stainless steel to epoxy resin was studied. In these experiments (also briefly described in Ref. 6), metal inserts were embedded in epoxy-resin casts (Fig. 1) and then exposed to gamma radiation in air.

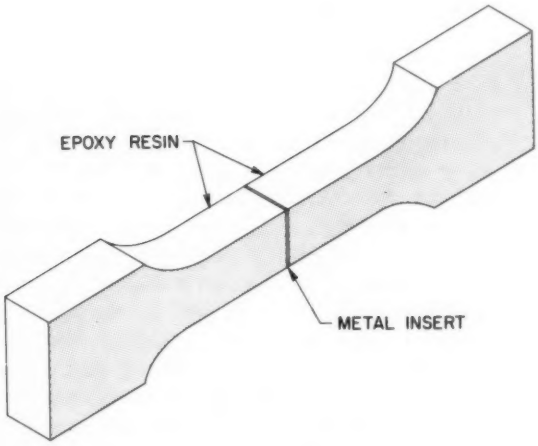

Fig. 1 Specimen for testing join strength between metal and epoxy resin.

The variability of the join strengths between the metal and epoxy polymer was determined after different doses of radiation, different stages of thermal precuring of the epoxy resin, and different surface treatments of the metal inserts. Boundary failure was observed when tensile force was applied to the grips of the specimens, and the strength of the joins was calculated from the recorded load at break and the area of the exposed face of the metal insert. Five specimens were used for each test set. The strength of joins of stainless steel to epoxy resin was found to be tripled after exposure to 6.0×10^7 rads, the increase being dependent on the surface treatment of the metal before it was embedded in the epoxy casts. Similar results were also observed with copper. An interpretation of metal–polymer adhesion is also given in the report.

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Patent Literature on Process Radiation and Irradiator Design. Part 1. United States Patents 1950 Through 1968*

By R. E. Greene, H. S. Warren, and P. S. Baker

(Summarized by R. E. Greene)

Supplementary Keywords: *review, technical; source, gamma; accelerator; industry; synthesis; food preservation; catalysis; modification, material; polymerization; cross-linking; grafting.*

Abstract: *A review of the U. S. patent literature from 1950 through 1968 on process radiation and irradiator design is presented. The search program for the identification of more than 700 relevant patents is briefly described, and an analysis of the patent collection reflects industrial interest in present and potential applications of ionizing radiation. This is a summary of USAEC Report ORNL-IIC-34.*

Because of the interest of the Division of Isotopes Development, U. S. Atomic Energy Commission, in process radiation development, the Isotopes Information Center has undertaken a review of U. S., British, and Canadian patent literature on process radiation to categorize, abstract, and compile the information and to analyze the findings.

Process radiation, for the purpose of the review, is defined as the use of high-energy radiation from accelerators, X-ray machines, or radioisotopes to produce a chemical, physical, or biological change in the production or processing of materials. Patents on the design of irradiators used in process radiation are also included.

The patents are classified into two major categories—process radiation applications and irradiator design. In the complete report, patent cards prepared for each patent disclosed in the search are reproduced in Appendix I, *Process Radiation,* and Appendix II, *Irradiator Design.* The cards contain the following information: patent number and country; date of issue and date of filing; assignee and patentee; patent category, i.e., process radiation or irradiator design; title; code class and international code class, where applicable; and description of the patent. The description of the patent includes either an abstract or the first or most important claim or claims given in the *Official Gazette of the U. S. Patent Office.*[1] Supplemental information verifying the use of radiation has been taken from the body of the patent when not adequately covered by the claims or abstract.

The report is to be presented in more than one part: Part I contains U. S. Patents from 1950 through 1968, with a partial listing of 1969 and 1970 patents appended. Part II will contain British and Canadian Patents. Copies of all patents listed are on file at the Isotopes Information Center.

LITERATURE SEARCH

One of the early significant sources of patent literature used for the search was *Patent Literature in Radiation Chemistry*, by Wentworth and Canfield.[2] The Isotopes Information Center's normal activities in scanning the literature on isotopes, including *Nuclear Science Abstracts*[3] and the accessions on file at the Center, provided other relevant patents. Additional sources of such information were not exploited fully, however, because of the availability of the IFI/Plenum Data Corporation [formerly Information for Industry, Inc. (IFI)] Uniterm Index to U. S. Chemical Patents[4a] on magnetic tapes for computer searching. Purchase of these tapes permitted searching of more than 220 thousand U. S. Patents for the years 1950 through 1968, using a vocabulary of more than 11 thousand terms.[4b] Tapes of new patents are issued periodically. This computer program is the major source of identification of the patents in this search, and checking of patents found through routine scanning activities of the Isotopes Information Center against patents retrieved in the computer search has demonstrated both the comprehensiveness of the IFI patent collection and the adequacy of the searching technique used for the review.

*Oak Ridge National Laboratory, P. O. Box X, Oak Ridge, Tenn. 37830. Report available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151. Full size, $3.00; microfiche, $0.95.

ANALYSIS OF FINDINGS

More than 700 U. S. patents relating to high-energy ionizing radiation for industrial processing were acquired by the Isotopes Information Center during the search.

Figure 1 shows the yearly growth in the total number of patents issued for irradiator designs and for process radiation applications. The growth exhibited in the number of patents issued per year during the first 10 years (1950 through 1959) was slow. Only 87 patents describing the use of radiation were granted during that period. Of these, 22 were concerned with irradiator and source designs.

Beginning with 1960, however, the patent literature on the use of radiation as an industrial processing tool increased significantly. More patents (100) involving irradiation were issued in 1963 than in any other year to date; 96 of these were for irradiation processes and 4 were for source and irradiator designs. The total rate of issue has varied, with a low of 50 patents in 1965. From 1960 through 1968, on an average, 69 patents per year have been granted, with about 10% of them concerned with irradiator and source design. More irradiator designs were patented in 1964 than in any other year (i.e., 12, or 20% of the total irradiator design patents from 1960 through 1968).

The spread of interest throughout industry in the use of radiation has continued to grow steadily and is indicated in Fig. 2 by the number of companies (assignees)* receiving patents in which high-energy radiation is used. In 1960, 82 patents using radiation were granted to 33 different companies. Since 1960, companies receiving patents have averaged 34 per year. The number of companies receiving irradiation patents for the first time averaged 15 per year for the period 1960 through 1968, as can be seen in Fig. 3. In

*Where there is no corporate assignee, the patentee was used as the assignee or company.

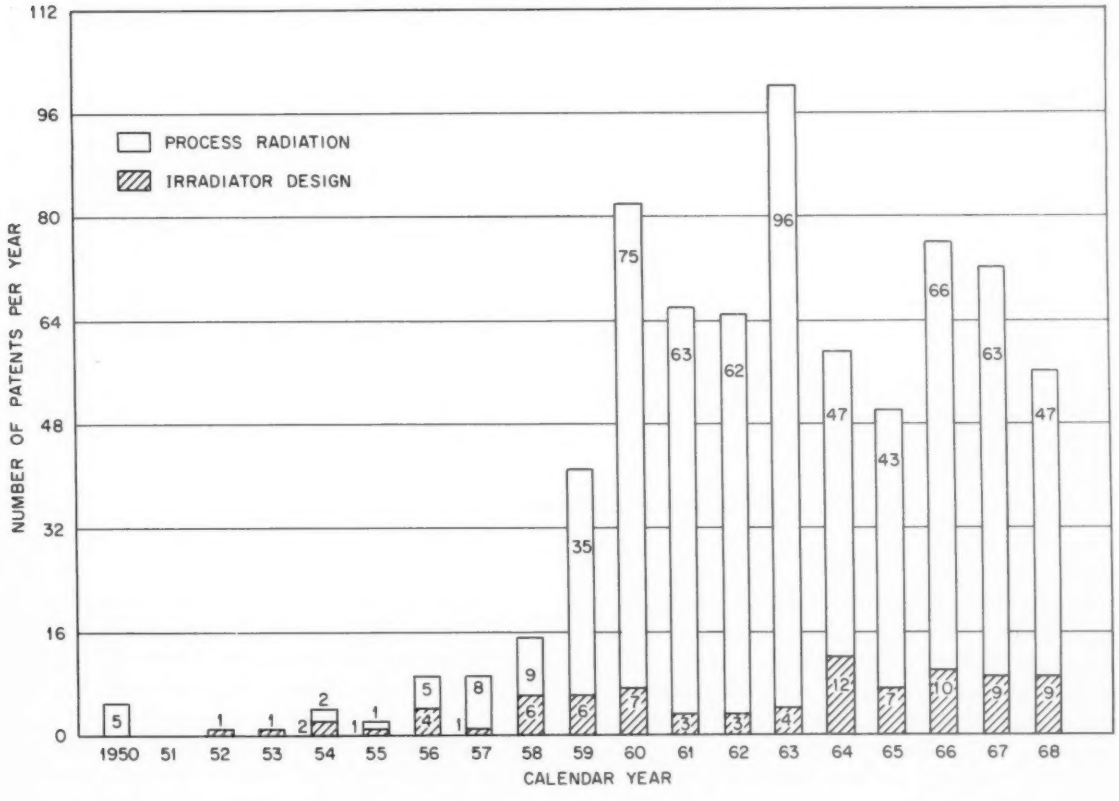

Fig. 1 Total number of radiation processing patents (includes both irradiator design and process radiation patents).

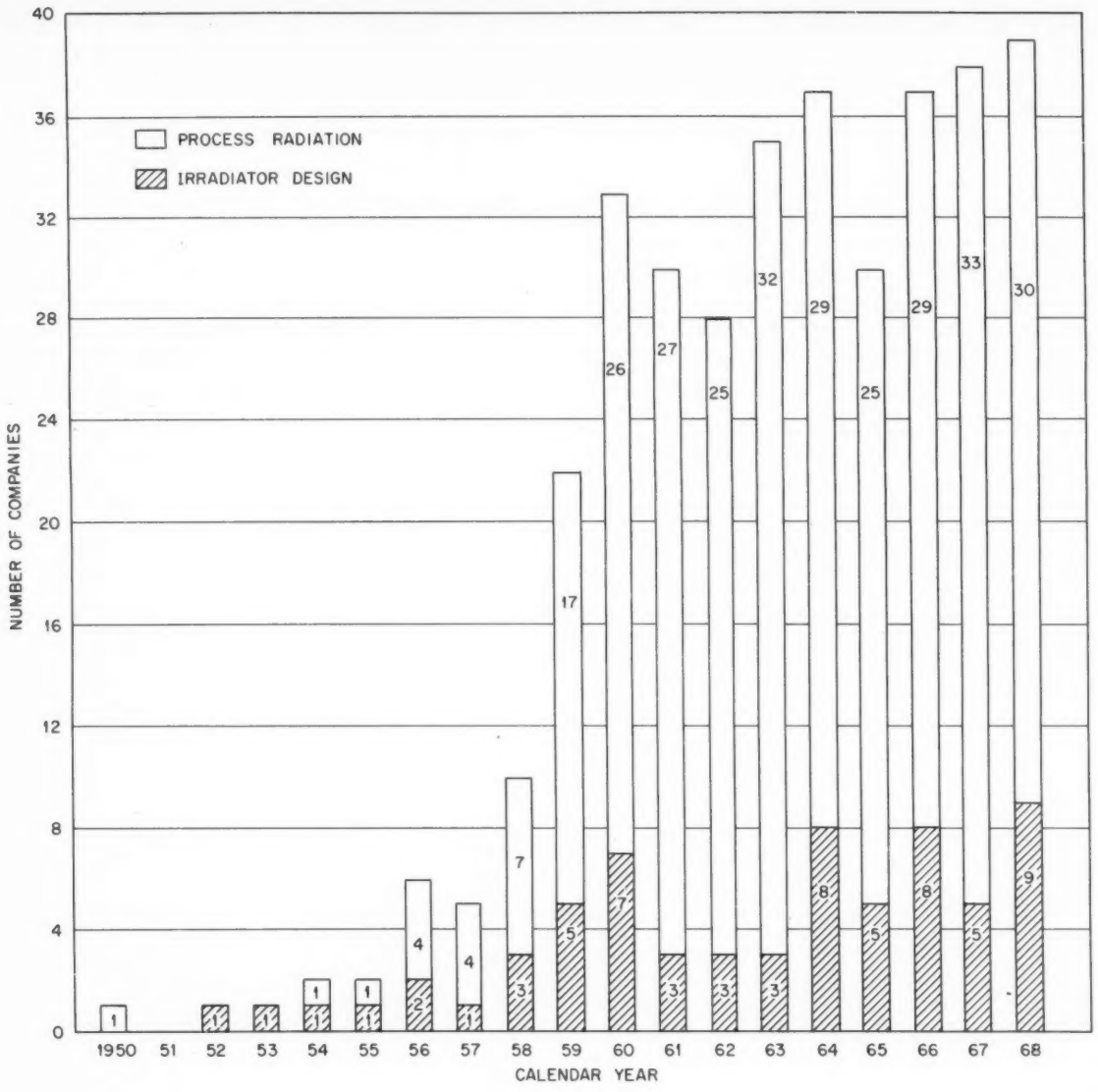

Fig. 2 Number of companies receiving patents.

1968 the 56 patents on the use of radiation were granted to 39 companies, 16 of which were new to the irradiation industry. Of 60 patents on radiation-induced synthesis (Fig. 4) which include processes for the preparation of such diverse products as amines, carboxylic acids, fluorinated compounds, and organo-metallic compounds, 10 were granted in 1966, with an average of 6 patents per year for the period 1960 through 1968.

The use of radiation in the modification of catalysts is indicated in Fig. 5. Here again, the first half of this same period was more productive than the latter half. The average number of patents issued was 7 per year.

Food preservation by irradiation received the early attention of the food industry (Fig. 6). Continued interest is evidenced by the fact that 35 patents on the preservation of foods have been granted, with 16 in the

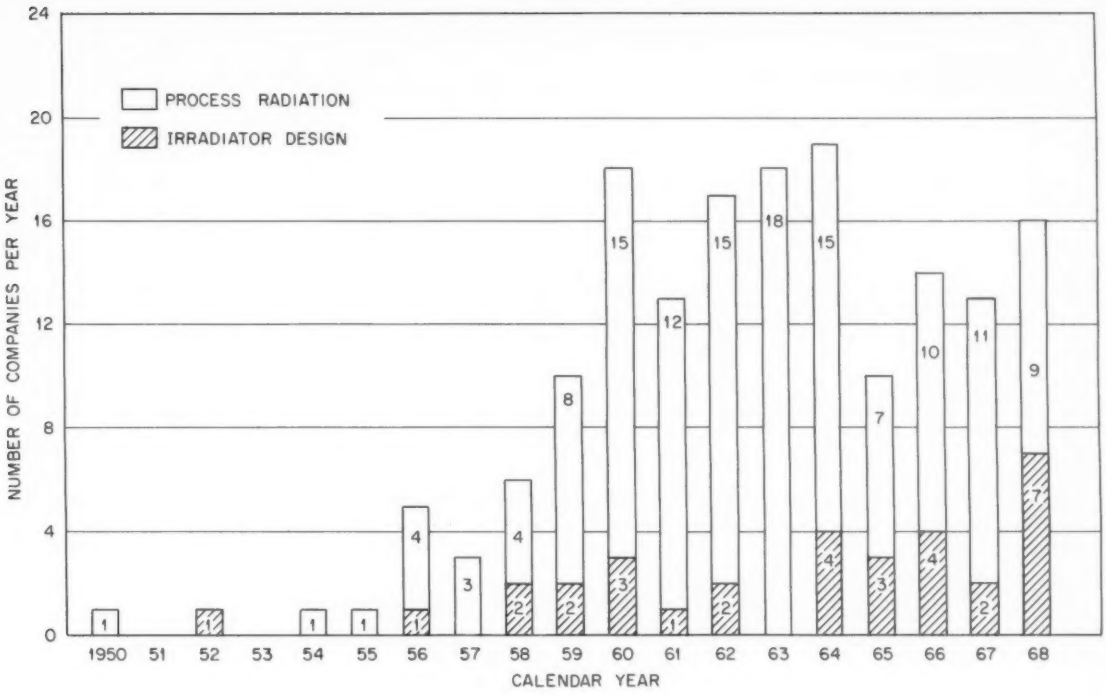

Fig. 3 New entries into the process radiation industry.

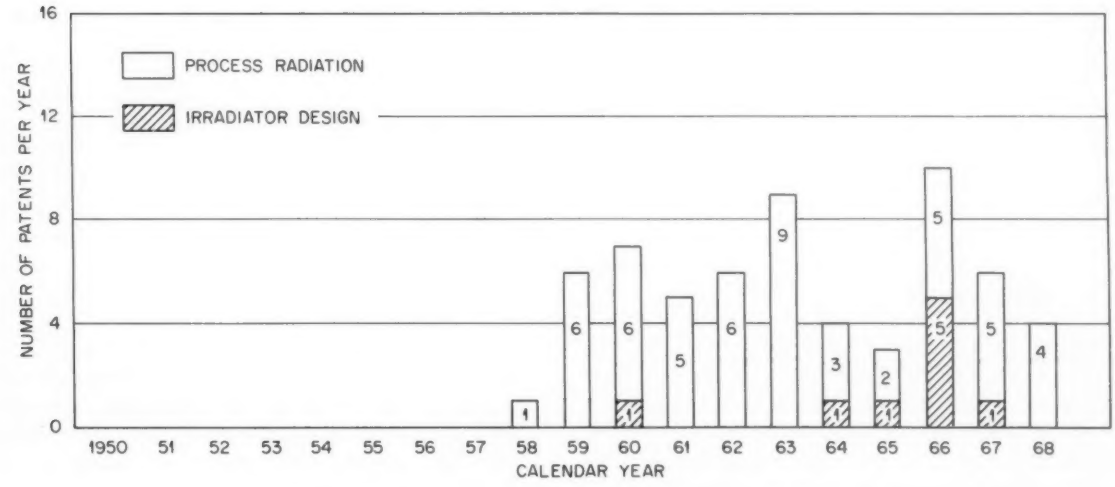
PROCESS RADIATION
IRRADIATOR DESIGN
NUMBER OF PATENTS PER YEAR
CALENDAR YEAR
0
4
8
12
16
1950 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68
1 6 6 5 6 9 4 3 5 5 4
1 1 1 1 1 5 1

Fig. 4 Radiation-induced synthesis.

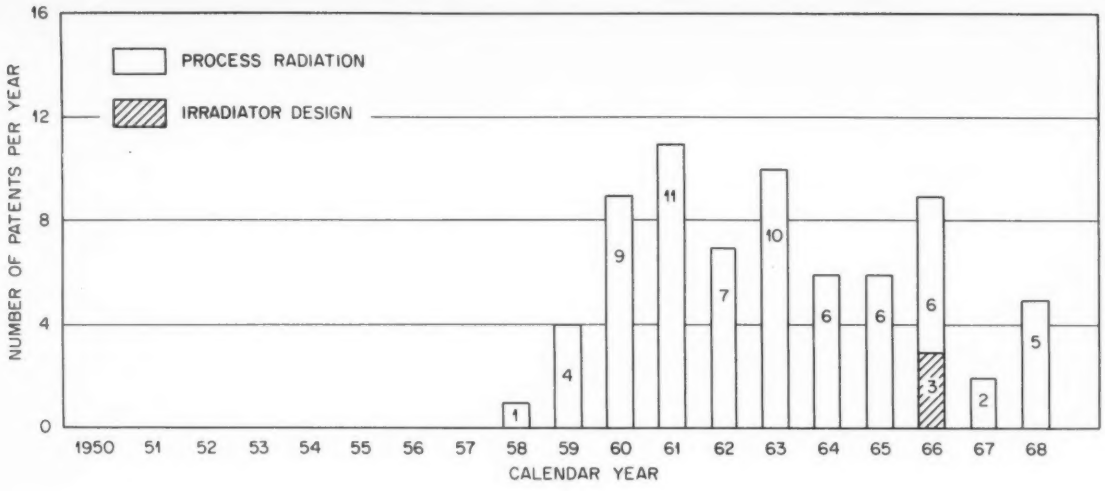

Fig. 5 Radiation modification of catalysts.

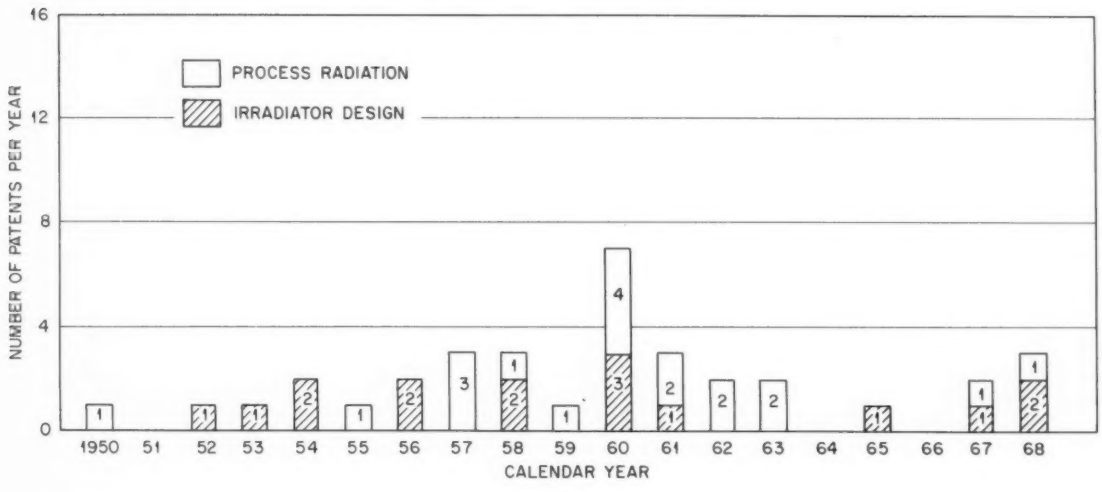

Fig. 6 Radiation preservation of food.

category of irradiator design. Seven patents is the largest number granted in any one year (1960), with 3 of them being irradiator design patents. The 16 irradiator design patents could represent a considerable industrial potential for irradiation processing when the various petitions for specific foods have been approved by the Food and Drug Administration.

The commercial importance of polyethylene is reflected in the issuance of 94 process radiation and 6 irradiator design patents concerned with its production and modification by grafting, cross-linking, etc. Although the peak years were 1960 and 1963 as shown in Fig. 7, innovations in the production of polyethylene and polyethylene products have continued in significant numbers, resulting in an average of 10 patents per year from 1960 through 1968.

The numbers of patents for polymerization and for cross-linking in the processing of various polymers result in similar graphs in Figs. 8 and 9, respectively; both show most activity in the early part of the 1960s.

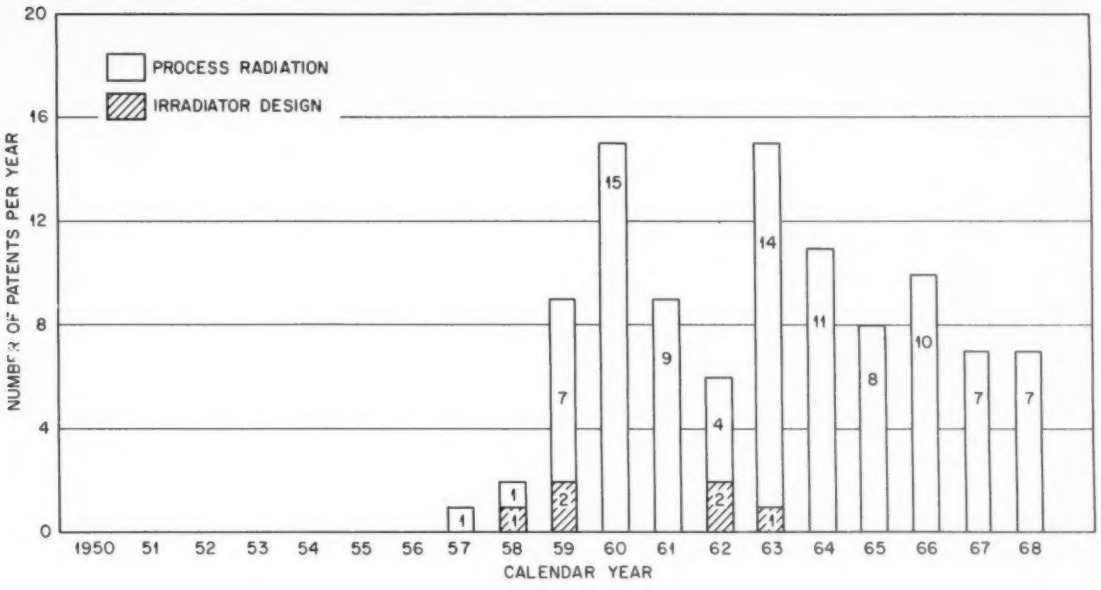

Fig. 7 Radiation production and modification of polyethylene.

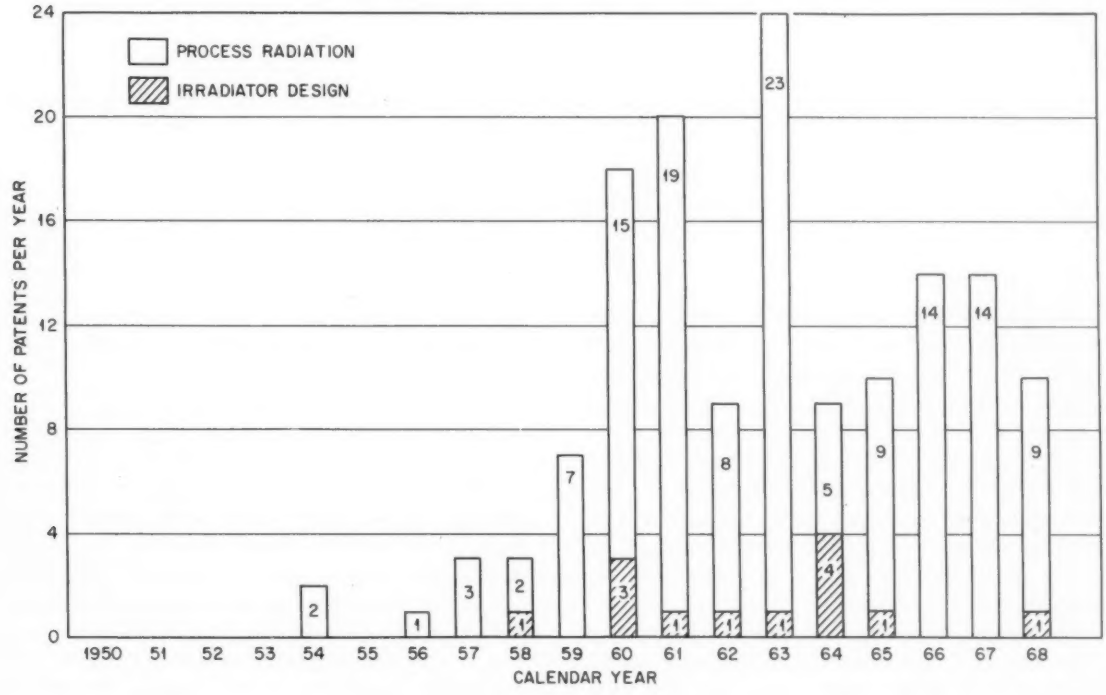

Fig. 8 Radiation polymerization.

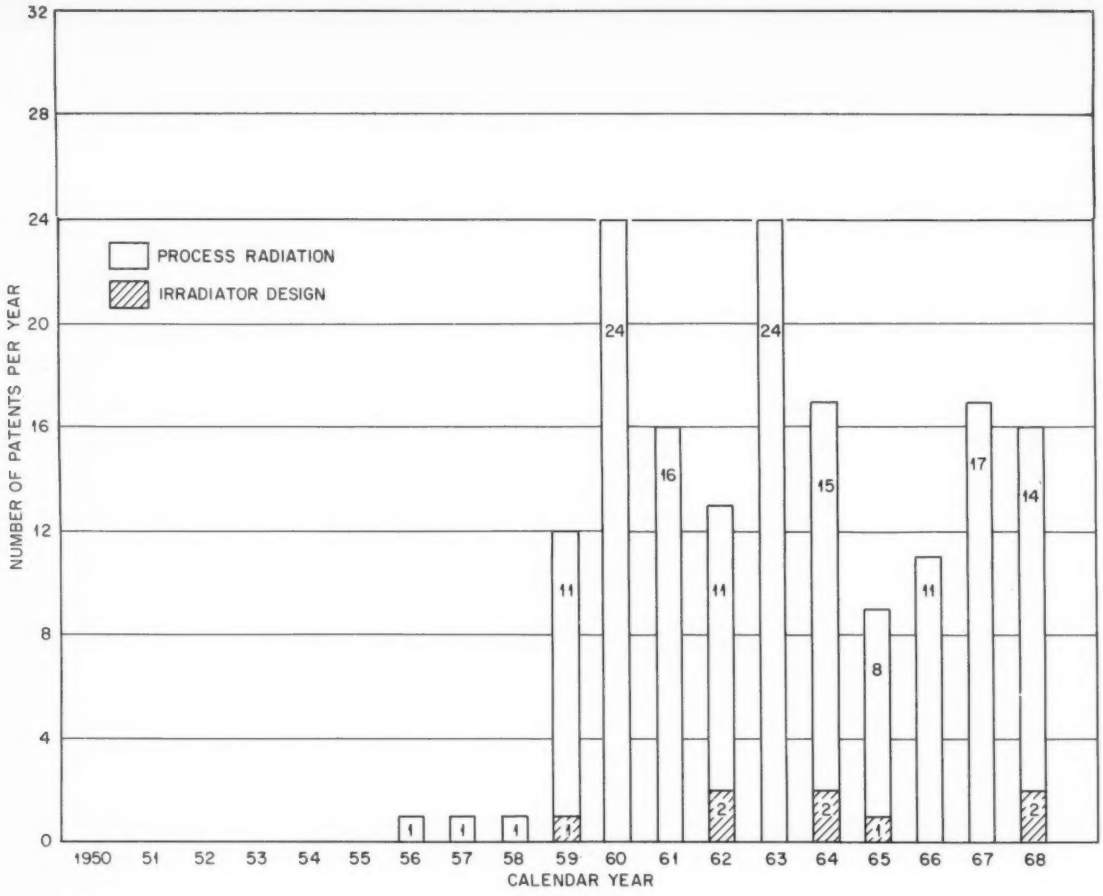

Fig. 9 Radiation cross-linking.

Twenty-four patents using radiation polymerization were issued in 1963, with a total of 128 for the 1960 through 1968 period. During this same period, an even greater number (147) involving cross-linking processes were granted, 24 in 1960 and again in 1963.

There were no radiation grafting (as distinguished from random or block copolymerization) patents until 1958. Interest in the process spread rapidly (Fig. 10), particularly throughout the textile industry, resulting in 18 grafting-process patents in 1966 with an average of 12 per year since 1960.

Table 1 lists some other uses of irradiation and the distribution of patents granted during the time period indicated. While these classifications are not large numerically, attention should be drawn to the interest exhibited in such processes as the polymerization of coatings, modification of fibers and films, improvement in ease of coloration and dyeability, and development of semiconductors.

Figures 11 and 12 indicate the chief types of radiation specified in the patent claims. The patents collected include all forms of high-energy ionizing radiation—X-ray, gamma, beta (from isotope disintegration), electron (from accelerators), alpha, neutron, proton, and deuteron. Many patents do not indicate any specific type or source of radiation; others may include an "umbrella" phrase covering all forms of radiations. Therefore patents were indexed by type or source of radiation only when the source was mentioned specifically in the claims. The growth patterns for irradiations with gamma rays and with electron accelerators are similar.

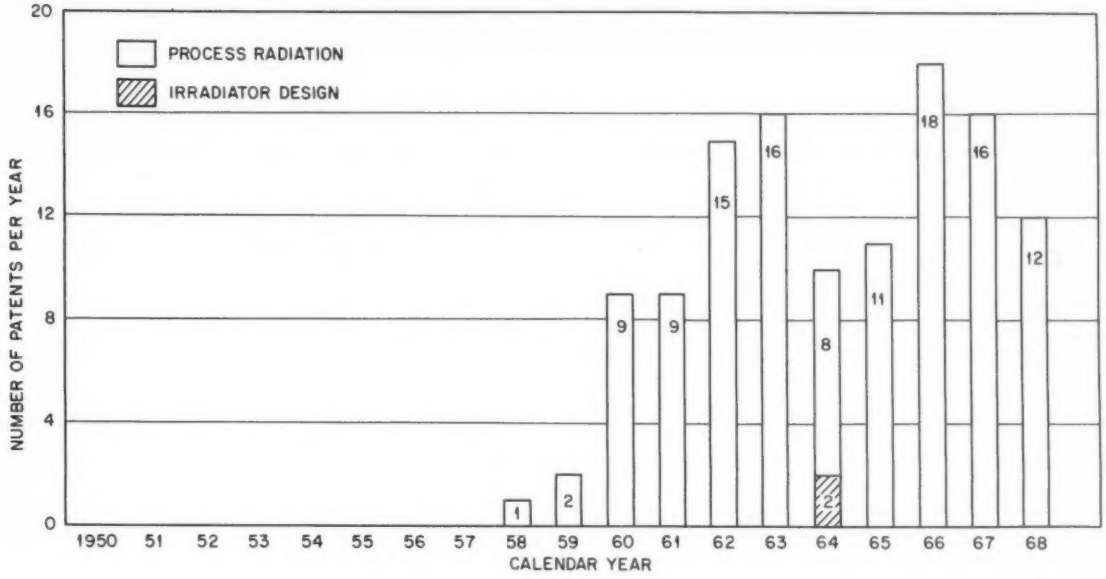

Fig. 10 Radiation grafting.

Table 1 Important Uses of Irradiation*

Use	Number of patents										Process radiation	Irradiator design	Total
	1950–1959	1960	1961	1962	1963	1964	1965	1966	1967	1968			
Bonding	3	–	1	3	–	1	1	1	1	3	14	–	14
Cellulose modification	1	1	3	–	2	1	1	5	2	2	18	–	18
Coating	2	3	2	–	3	2	5	2	–	6	23	2	25
Dyeability improvement	–	2	4	13	1	2	3	8	2	–	35	–	35
Fiber production and modification	–	3	4	12	6	3	7	9	4	1	49	–	49
Film production and modification	3	2	1	5	7	6	4	3	5	2	33	5	38
Foam-plastic stabilization	1	5	2	1	1	–	–	–	–	–	10	–	10
Insulation modification	–	2	2	–	–	2	2	–	–	1	9	–	9
Lattice displacement	3	–	2	–	3	–	1	1	1	–	11	–	11
Rocket-fuel stabilization	–	1	1	2	–	2	3	–	1	–	10	–	10
Semiconductor modification	3	–	–	1	2	–	3	3	2	2	15	1	16
Shrink plastic production	–	–	–	2	2	3	–	1	3	2	11	2	13
Stabilization	10	4	6	2	12	1	–	1	–	2	36	2	38
Surface treatment	1	3	–	–	–	–	–	–	–	2	5	1	6
Vulcanization	1	2	–	1	4	1	–	–	1	1	11	–	11
Wood–plastic production	–	–	–	–	4	–	–	–	–	1	5	–	5

*In addition to those discussed in the report.

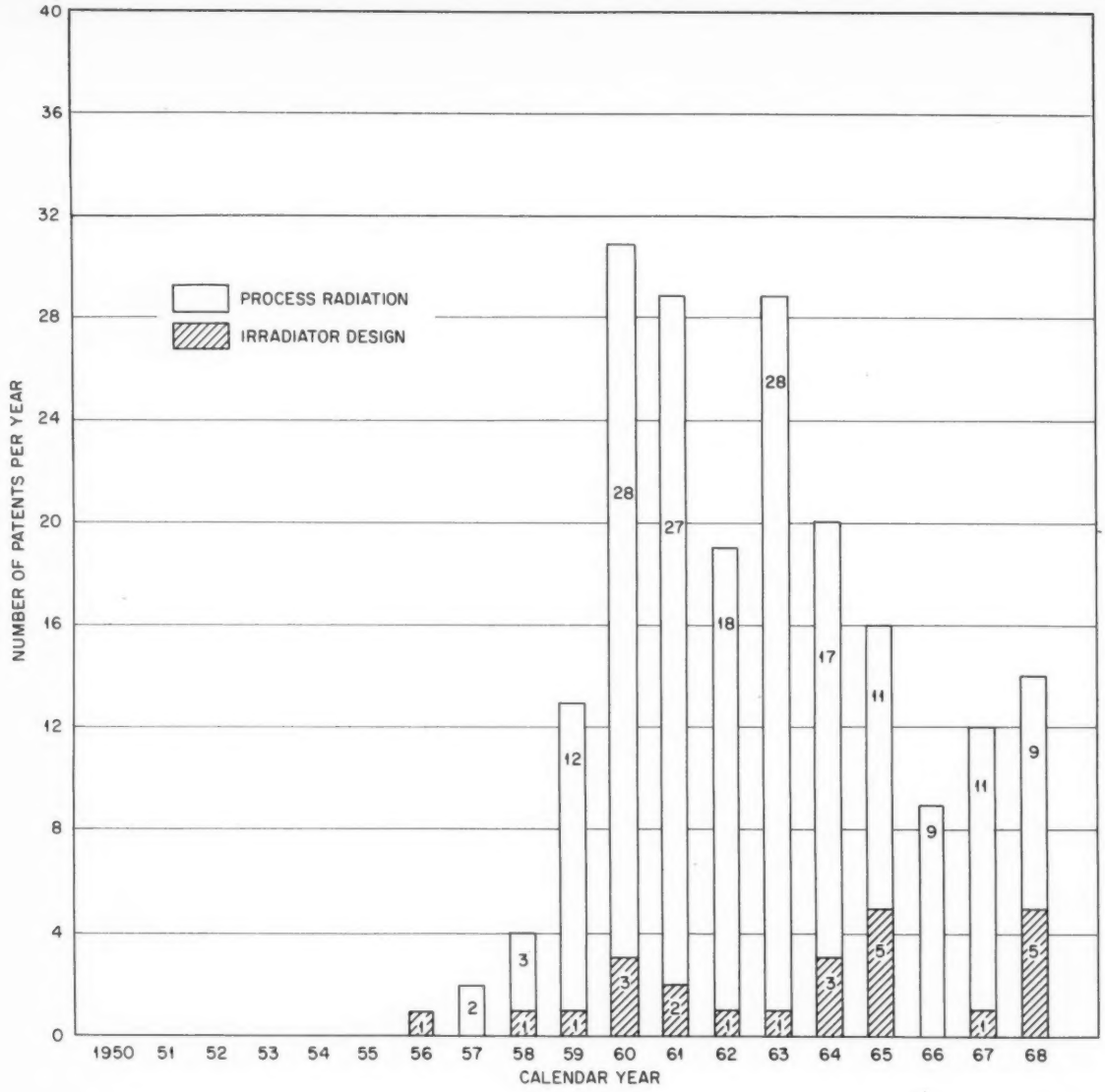

Fig. 11 Gamma-radiation patents.

APPENDIXES

The patent review contains three appendixes: *Process Radiation* (Appendix I), *Irradiator Design* (Appendix II), and a partial listing of 1969 and 1970 patents (Appendix III). In Appendixes I and II the patent cards have been reproduced and are listed in numerical order. Separate subject and assignee indexes have been prepared for each category. In many cases a patent covers both method and apparatus, and it was necessary to make a choice of category to avoid duplication.

Corporate assignees are listed in separate indexes.

Partial listings of 1969 and 1970 patents obtained through routine scanning procedures of the Isotopes Information Center are included in the two categories in Appendix III. These listings contain patent numbers, titles, and assignees.

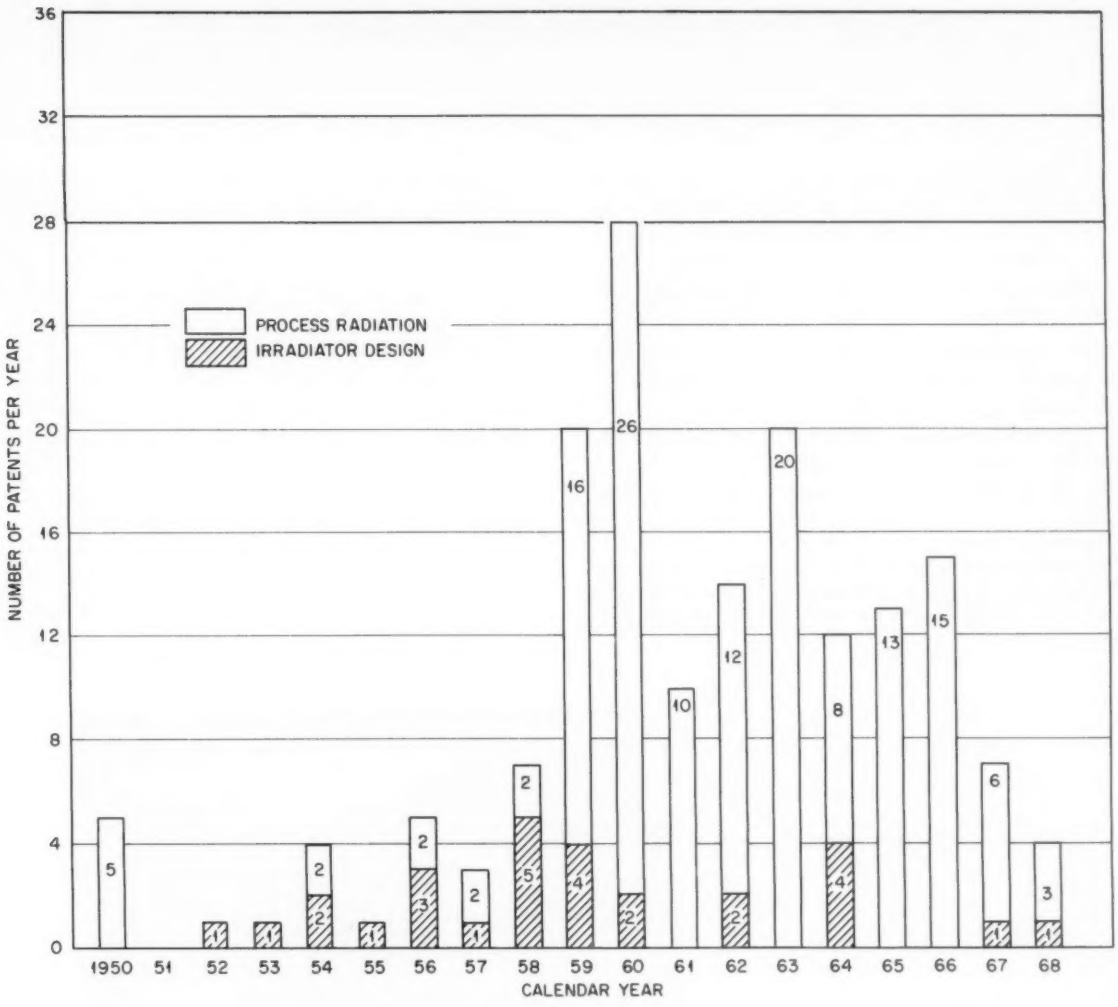

Fig. 12 Electron-radiation patents.

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3. *Nuclear Science Abstracts,* Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402.
4. *a. Uniterm Index to United States Chemical Patents,* IFI/Plenum Data Corporation, 1000 Connecticut Avenue, N.W., Washington, D. C. 20036, 1950–1968.
   b. Vocabulary of Chemical Terms Used in United States Patents, Fourth Edition, IFI/Plenum Data Corporation, 1000 Connecticut Avenue, N.W., Washington, D. C. 20036.

Italian Pilot Gamma-Irradiation Plant*

Supplementary Keywords: *source, gamma; facility description;* ^{60}Co.

A gamma-irradiation plant is located at the Casaccia Nuclear Studies Center of the Italian National Committee for Nuclear Energy (CNEN) in Rome. Designed for a 100-kCi source eventually, its present source strength is 60 kCi. It is used for experimental irradiations of agricultural products and for production of sterile insect males with the objective of improving techniques for these procedures and obtaining data for use in scale-up to industrial size.

The source is made of 48 small ^{60}Co rods, 15 Ci/g, fixed in a frame attached to a base that can be moved into the irradiation chamber when an irradiation is to be made. When not in use, the source is located in a 7-m-deep pool, the water of which serves as a biological shield.

Items to be irradiated are placed in 65- by 30- by 35-cm containers, which are suspended from a monorail carrier and transported into the cell through an L-shaped corridor. Recently, a rotating platform, 1 by 1 m and with a capacity of 1000 kg, and symmetrical with respect to the source, was constructed on which the item to be irradiated can be placed. As this platform rotates at 1 rpm, a homogeneous dose ranging from rads to megarads can be administered to the product, e.g., potatoes in a 1-m^3 wooden crate, with a total weight of 700 kg (Fig. 1).

Because of its experimental nature, the plant was designed to be very versatile and to operate on products of various types. (MG)

*Summary of report No. 280 by Delio Baraldi, Laboratorio Applicazioni in Agricoltura della Casaccia, Rome, published in Italian in *Radiazioni e Radioisotopi*, 4(1): 13-18 (January–March 1971).

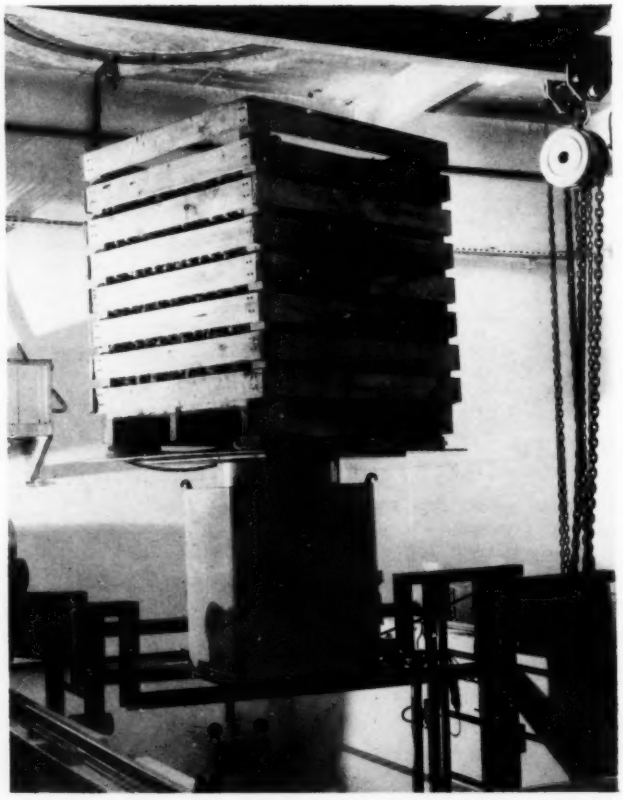


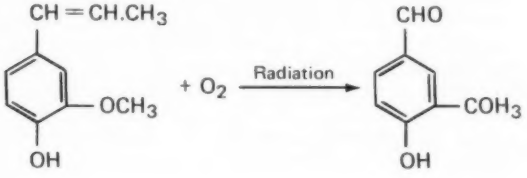
Fig. 1 Rotating platform of Casaccia pilot gamma-irradiation plant.

Ionizing Radiation Used To Produce Perfume

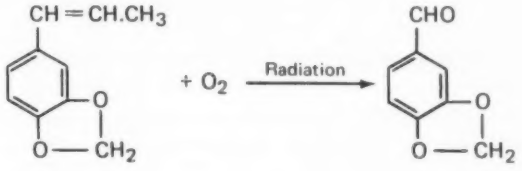
Supplementary Keywords: *source, gamma; accelerator; industry, chemical; chemistry, organic; method; patent; Japan.*

Vanillin and heliotropin are commonly used as additives to foods or toilet articles or as bases of scents. Their consumption throughout the world is increasing greatly. By use of ionizing radiation, it is now possible to produce these compounds in good quality at high yield and low cost compared with the earlier methods of ozone or other chemical oxidation.

The compounds are produced in ~100% yield by the irradiation of phenol derivatives. Gamma irradiation of isoeugenol gives vanillin; the reaction is



With high-speed electrons from a linear accelerator, heliotropin is produced from isosafrol:



U. S. Patent No. 3,326,786 on the process is issued to the Japanese inventors, S. Kinoshita and T. Sunada, assignors to G. Sato, Governor of Osaka Prefecture, Kigashi-Ku, Osaka, Japan.

(HPR)

Concrete–Polymer Materials Program

By Meyer Steinberg*

Supplementary Keywords: *industry, stone, clay, and glass; industry, building; industry, mining; industry, transportation; polymerization.*

The objective of the concrete–polymer program in the Department of Applied Science at Brookhaven National Laboratory (BNL) is to develop and apply new and improved concrete materials of construction. Three distinct types of materials are being investigated: (1) polymer-impregnated concrete (PIC)—a precast portland-cement concrete impregnated with a monomer that is subsequently polymerized in situ; (2) polymer–cement concrete (PCC)—an uncured mixture of monomer and portland-cement concrete mix that is subsequently cured and polymerized; and (3) polymer–concrete (PC)—an aggregate mixed with a monomer, which is subsequently polymerized (this mixture contains no portland cement). PIC has demonstrated the greatest advance in improved structural and durability properties. PC is a relatively new development and shows much potential. PCC has shown the least promise for enhancement of structural and durability properties. Monomer polymerization initiation by several agents was compared: (*a*) ^{60}Co gamma radiation, (*b*) heat and catalyst, (*c*) catalyst and accelerator, and (*d*) combinations of these agents.

The basic program is sponsored by the Division of Isotopes Development, USAEC. The tasks involve (*a*) monomer survey; (*b*) study of process technology; (*c*) measurement of physical, mechanical, and chemical properties; (*d*) fundamental studies; and (*e*) applica-

*Radiation Processing Section, Department of Applied Science, Brookhaven National Laboratory, Upton, N. Y. 11973.

tions development. Several other government agencies are cooperating in arrangements for developing concrete–polymer material for specific applications:

1. The Bureau of Reclamation of the Department of the Interior is cooperating with BNL in developing concrete–polymer materials and is sponsoring experimental work in the Bureau's Denver laboratories. The Bureau is interested in developing improved concrete materials for pipe, drain tile, water-tunnel linings and other water carriers, and such civil-engineering works as dams. The American Concrete Pipe Association is also cooperating in investigating concrete–polymer for pipe.

2. The Office of Saline Water is sponsoring work at BNL and the Bureau of Reclamation for developing concrete–polymer materials for construction of distillation vessels for water desalination. PIC has been developed with a strength four times that of ordinary concrete and resistance to chemical attack during distillation of hot brine at temperatures up to 290°F.

3. The Federal Highway Administration's Bureau of Public Roads is sponsoring work at BNL in conjunction with a testing program in the Bureau's own Fairbanks Research Laboratory, McLean, Va., on concrete–polymer materials for highway applications. These include (*a*) lightweight PIC concrete for breakaway lamp and sign posts, (*b*) standard and structural lightweight PIC for precast bridge decks, and (*c*) partially impregnated concrete–polymer to improve the durability of installed highway and pavement surfaces.

4. The Naval Civil Engineering Laboratory is sponsoring work in its own laboratories in Port Hueneme, Calif., on development of PIC for underwater structures. These include buoys for carrying instruments and telemetry equipment, underwater manned habitats, and large underwater offshore storage vessels.

5. The U. S. Department of Agriculture has made some tests at BNL on concrete–polymer as a possible low-cost housing material for migrant workers.

6. The U. S. Bureau of Mines is sponsoring work at BNL on underground support structures in conjunction with the Bureau's Coal Mines Safety Program. The tasks include study of the strengthening of mine walls by a monomer-impregnation technique and subsequent curing in situ. Another development is a roof bolt that can be installed remotely by pumping to the desired location a monomer that is subsequently polymerized in place. This development could prevent accidents that occur during the placement of a steel roof bolt just behind the coal seam face where a miner must stand beneath an unsupported roof while placing the bolt. (REG)

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USSR LMB and RKh Irradiators*

Supplementary Keywords: *facility description;* ^{60}Co; ^{137}Cs.

BIOLOGICAL IRRADIATOR

The USSR LMB irradiator using ^{137}Cs or ^{60}Co is designed for research in such fields as microbiology, biochemistry, and genetics. The lead-shielded facility (Fig. 1) has six linear radiation sources arranged symmetrically around the cylindrical (10 cm high, 6 cm in diameter) irradiation chamber. Two spiral tubes in the upper shielding plug provide for introduction to the irradiation chamber of gas or liquid to be irradiated and for entry of electric wires. Depending on the needs of the user, the facility may be fitted with radiation sources varying in strength from 480 to 2600 Ci.

The facility is easily put into operation. By means of a control button, the irradiation chamber is moved outside the source radiation zone—actually, outside the main body of the unit. The chamber cover is lifted, the object to be irradiated is inserted, the cover is replaced, and the chamber is moved back into the

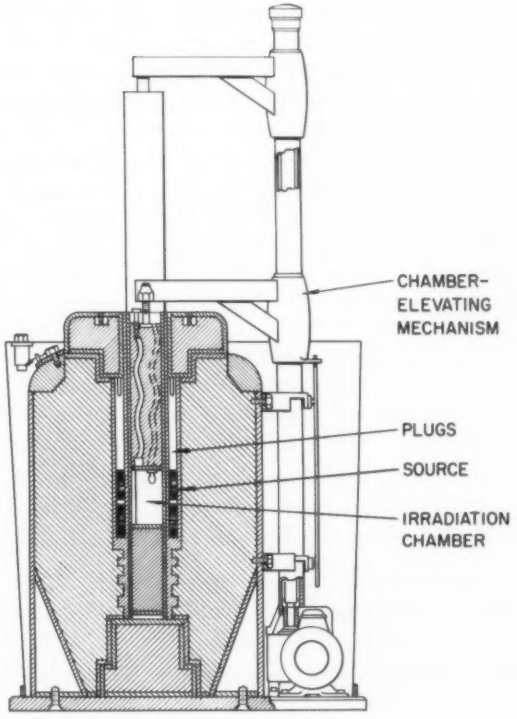

Fig. 1 Biological research irradiator, LMB.

*Summary of an article (in French) by D. A. Kaouchanski in *Energie Nucleaire*, **12**(3): 239-242 (1970); the RMKh model is also described (in German) in *Isotopenpraxis*, 7: 349-350 (1971).

radiation zone, where it remains until the object under study has been given the desired dose.

The dose rate at the surface does not exceed 2.8 mR/hr and is less than 0.28 mR/hr at 1 m. Thus the facility can be shipped by any means of transportation.

INDUSTRIAL IRRADIATORS

The RKh irradiator (Fig. 2) is designed for industrial research—e.g., for modifying polymers, synthesizing chemicals, sterilizing medical products, processing foods, and irradiating insects for use in sterile-male control programs. The volume of the irradiation chamber, which is in the center of the unit, is 4.4 liters for the RKh model; the RMKh has, in addition, a 0.7-liter lateral chamber. Experiments can be done under static or mobile conditions at temperatures of −40 to +550°C and at pressures from 10^{-5} to 7600 torrs. The chamber can be moved out of or into the radiation zone in 30 sec.

The cylindrical source holder, which surrounds the irradiation chamber, is made up of 36 tubes, each containing three ^{60}Co sources doubly encapsulated in stainless steel (11 mm in diameter, 81.5 mm high). Model RMKh-γ-30 has a source strength of 16.2 kCi and RMKh-γ-20, 12.5 kCi. Dose rates are 1.3 to 1.6×10^6 and 0.9×10^6 R/hr, respectively, each with about 25% uniformity. The dose rate at the surface of these installations is 2.8 mR/hr.

An RKh-30 unit has been installed at the State Forest Products Research Institute in Bratislava, Czechoslovakia.[1] This unit had a source strength at the time of installation of 7730 Ci, but its capacity is 1 MCi. (MG)

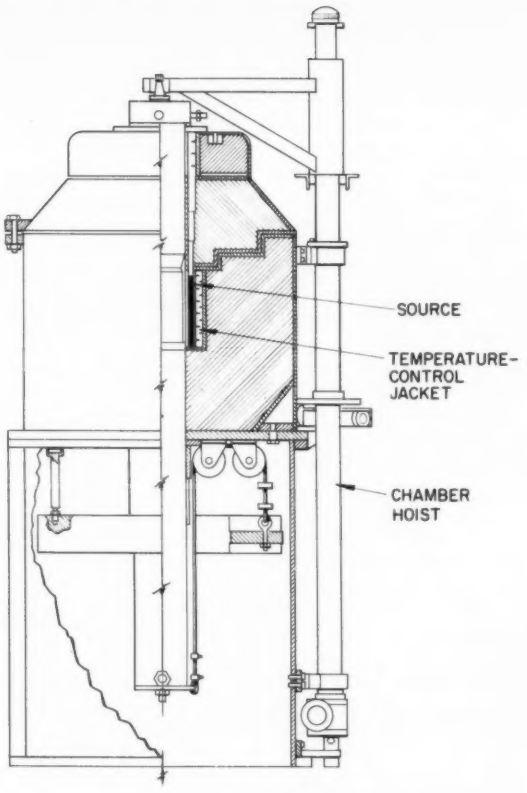

Fig. 2 Industrial research irradiator, RKh.

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Section
IV
Isotopes and Radiation Technology

Isotopic Heat and Power Development

U. S. Navy Radioisotopic Power Generator Program

By R. P. Cope* and T. P. Fleming*

Supplementary Keywords: *energy source; military.*

Abstract: *The Navy Radioisotopic Power Generator (RPG) Program is managed and administered by the Naval Facilities Engineering Command (NAVFAC) and its field office, the Naval Nuclear Power Unit. The RPGs convert heat directly to electricity, operating on the thermocouple principle, and are used in inaccessible areas where long-life unattended power sources are required. Current prices of RPGs range from $45.5 thousand for an 8-W unit to $63.7 thousand for a 25-W unit. Units that produce up to 2 kW are expected to be available by 1976, and near-future Navy efforts are expected to be concentrated in the higher power units.*

On a windy and fog-shrouded plateau of a remote uninhabited Pacific island, vital weather data are being automatically collected and transmitted to a Navy control center on the California coast. Power for the operation is supplied by a radioisotopic SNAP (*S*ystems for *N*uclear *A*uxiliary *P*ower) energy source. Evaluation of data from this and other such weather stations will determine whether or not important air and space missions will proceed as scheduled.

Providing of uninterrupted power to remote surface and deep-ocean installations has been a continuing logistics problem for Navy engineers, and the Atomic Energy Commission's (AEC) development of the radioisotopic power generator (RPG) enabled the Navy to take a long step forward in the solution of this problem. Continuous-service test operation of the SNAP-7D RPG in the Gulf of Mexico has now exceeded 7 years, and the RPG is still providing power although the buoy is in port for refurbishment. This and other similar demonstrations of integrated electronic systems utilizing radioisotopic power have enabled the Navy to expand the application of isotopic power.

Currently, the U. S. Navy is the free world's largest user of RPGs. The Navy achieved this leadership by early recognition of the unique capability of the RPG to supply long-life unattended power in almost any environment. Anticipating increasing requirements for power in surface, deep-ocean, and arctic environments, the Navy service-tested AEC-developed SNAP RPGs in surface buoys in the Gulf of Mexico, on the ice plateaus of Antarctica, and in ocean depths down to 15 thousand ft. In 1966, the Navy procured and used the first commercial-version RPG designed on the basis of AEC technology and offered as "off-the-shelf" hardware. Since then, many additional units have been procured, and the experience acquired has been made available to the whole Navy establishment through NAVFAC.

This article describes the major facets of the Navy RPG Program and provides answers to questions most often asked about it—questions of program management; operation and application of RPGs; and forecasting of future needs.†

ORGANIZATION AND MANAGEMENT

The primary goal of the Navy RPG Program is to develop and expand the effective use of RPG systems in Navy military applications. The most important secondary goals are to expand the availability of RPGs

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†Overall radioisotopic systems were summarized in *Isotopes and Radiation Technology*, 9(2), pages 230–239.

at power levels of 100, 200, 500, 1000, and 3000 W(e); to reduce unit costs by encouraging cost engineering, quantity procurements, and competitive award contracts; and to maintain safe operation of RPGs while minimizing the documentation required to obtain installation-permit and license approvals.

The program is an outgrowth of the Navy Nuclear Shore Systems Program, established by the Chief of Naval Operations in 1960. Initially a small cadre of nuclear engineers was organized under the Chief of the Bureau of Yards and Docks Headquarters and its field activity, the U. S. Naval Nuclear Training Unit, to manage and operate the PM-3A Nuclear Power Plant in Antarctica. By the end of 1966 these organizations had been renamed the Naval Facilities Engineering Command (NAVFAC) and the Naval Nuclear Power Unit (NAVNUPWRU), respectively, and the responsibility has been expanded to include radioisotopic energy applications. The Nuclear Power Division of NAVFAC provides program and technical coordination for the development and application of both reactor and radioisotopic nonpropulsive nuclear power within the Navy, while NAVNUPWRU, under the direction of NAVFAC, provides field services for support of Nuclear Shore Systems.

The Nuclear Power Division manages the program. It holds the Navy broad license issued by the AEC under which the Navy can operate RPGs throughout the world, approves the use of RPGs under this license, and ensures their safe application. It coordinates the development and use of RPGs in the Navy, participates in aerospace-launch safety approval of Navy satellite systems using nuclear power, and maintains close liaison with Navy users, AEC, and industry for the most effective utilization of RPGs and for ensuring that fuel and hardware will be available to meet future Navy requirements. It formulates policy governing the kind and amount of support that NAVFAC can supply RPG users, and it establishes guidelines for RPG specifications and procurements.

RPGs have been demonstrated to be extremely safe and reliable and to serve Navy power requirements very effectively in remote areas and severe undersea environments. What other power source has produced power unattended at 15-thousand-ft ocean depths for periods exceeding 5 years? The SNAP-7E did this and, furthermore, after 7 years was reassigned to a second mission, supplying power for integration testing of a new generation of automatic weather stations. Sufficient development has been completed by the AEC to demonstrate that RPGs can be produced in power ranges from milliwatts to kilowatts, and indications are that prices can be decreased by an order of magnitude by appropriate cost-engineering procedures and quantity production.

Technical advances are also extending the operational lifetime from the 5 years now found feasible to 10 to 20 years, primarily by improving thermoelectric converters and shock capability. Safety documentation can be streamlined as confidence is gained through test and operational experience; and requirements for installation, communications, and engineering analysis to obtain an installation license can be decreased as operating experience is gained. Progress toward these goals will facilitate deep-sea implants, simplify license applications, and effect major savings in both time and money.

NAVY RPG PROGRAM

RPGs developed by the AEC have been supplied to the Navy under a "Memorandum of Understanding." The SNAP-7C, the first RPG in the Navy program, was acquired in February 1962 and supplied power to a 5-W(e) portable automatic weather station (Fig. 1) at a remote location in the Antarctic. The initial output was 10 W(e), which decreased to 3.5 W(e) after 6.5 years. Since the 3.5-W(e) power level was insufficient to meet weather-station requirements, the unit was returned to the AEC in March 1969.

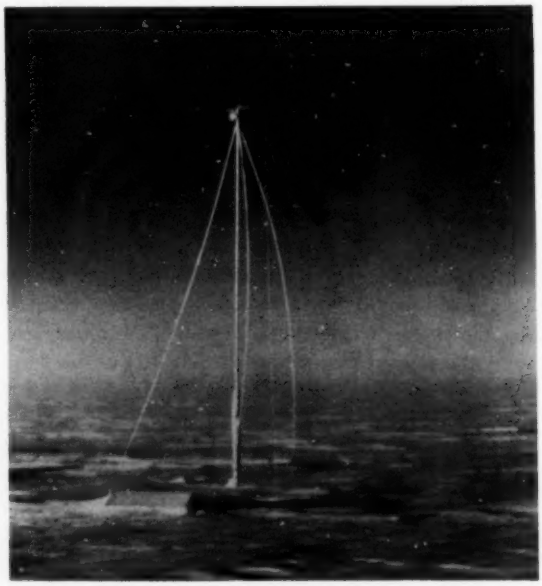


Fig. 1 Portable automatic weather station (SNAP-7C).

The SNAP-7D RPG, acquired in January 1964, was the first to power an unattended floating weather station. The NAVAIR NOMAD weather buoy (Fig. 2), implanted in the Gulf of Mexico, measured and transmitted meteorological and oceanographic data to shore receiving stations. The initial output of 71 W(e) decreased to 43 W(e) in 7 years, and in September 1969 the unit was retrieved for refurbishment of the buoy and instrumentation.

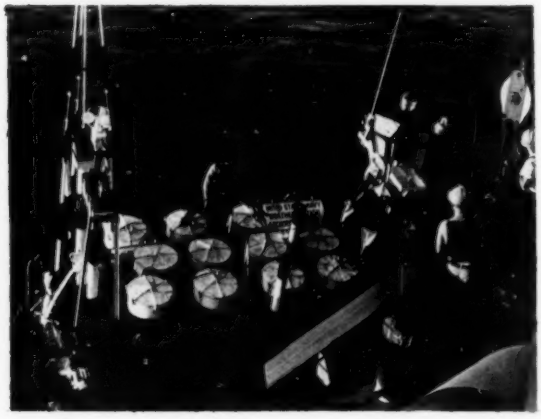


Fig. 2 SNAP-7D NOMAD weather buoy.

The SNAP-7E, acquired in July 1964, powered a deep-ocean acoustic beacon for the Naval Underwater Systems Center. The initial output was 6.4 W(e). The unit was implanted in 15.9 thousand ft of water and operated successfully until September 1968, when acoustic transmission ceased. On Nov. 25, 1969, it was recovered from the deep ocean without incident (Fig. 3). Failure was due to the loss of the transducer after corrosion of stainless-steel strain-relief members caused the riser cable to break. The SNAP-7E RPG was returned to Oak Ridge National Laboratory, and in November 1970 it was shipped to the U. S. Naval Avionics Facility at Indianapolis, Ind., where 7.5 years after construction, its 4.8-W(e) output is being used as a power source for developing a prototype family of portable automatic weather stations.

The Naval Undersea Research and Development Center (San Diego), under AEC sponsorship, conducted an isotopic power environmental-test and radiological-effects program. Three SNAP-21 (Fig. 3) RPGs were implanted in approximately 100 ft of water—one unit 6 in. beneath the ocean floor and the other two located 1 ft and 5 ft, respectively, above the ocean floor. The units were designed to operate at a depth of 20 thousand ft and to produce 10 W(e) of power at the end of 5 years, with a beginning-of-life unconditioned power output of approximately 14.5 W(e). Each generator system was monitored for internal temperature and power-generating parameters, from which the operating characteristics were determined. In June 1970, the unit 1 ft above the ocean floor was recovered and transferred, with another fueled unit, to the Naval Underwater Systems Center. The two units were integrated into deep-ocean pinger systems, and one system was implanted in international waters of the Atlantic Ocean. This implant was the first under a new AEC–Navy Memorandum of Understanding whereby the Navy is responsible for safe usage under the broad license issued by the AEC. The major difference in this procedure from that previously used is that the AEC no longer personally supervises SNAP RPG operations from a safety point of view. Instead, Navy health-physics and operation records are reviewed under the terms of the broad license.

Another historical RPG ocean implant was the NAVOCEANO IRLS (*I*nterrogation, *R*ecording, *L*ocation *S*ystem) Platform, which was anchored in 4350 ft of water southeast of Puerto Rico in April 1968. Power for measuring oceanographic data and transmitting it to shore receivers and the Nimbus-B satellite was supplied by a 25-W(e) RPG, the first licensed by the AEC for implantation in the ocean. After a successful demonstration, the unit was transferred to the Naval Undersea Research and Development Center for use in a Pacific Ocean implant, where it continues to operate.

The Navy supplied 25-W(e) RPGs for two other programs of short duration—the Pacific Sea Spider

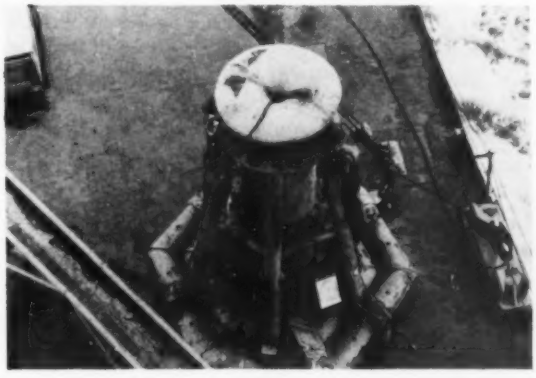


Fig. 3 SNAP-7E acoustic beacon.

under the Office of Naval Research and the Cosmos—Stable Platform Array under NOAA (*N*ational *O*ceanic and *A*tmospheric *A*dministration). Both installations used RPGs in subsurface ocean buoys. The Pacific Sea Spider was the first installation to use three RPGs integrated to provide 100 W(e) of power initially. The Cosmos buoy used one 25-W(e) RPG.

In a test on the operating characteristics and reliability of RPGs conducted at the Naval Civil Engineering Laboratory during 1967–1969, performance was satisfactory for all units tested:

Model	Navy No.	Manufacturer	Nominal power, W(e)
NW-3000	RTG-2	Isotopes, Inc.	3
RIPPLE III	–	UKAEA	0.75
Sentinel-25B	–	Isotopes, Inc.	25
URIPS P1	RTG-3, RTG-5	Aerojet General	1 (each)

The joint AEC–Navy programs, using the SNAP-7D, SNAP-7E, and SNAP-21 RPGs, are continuing. In addition, the NAVAIR NOMAD buoy program was expanded in mid-1970, when three new buoys, each powered by a 25-W(e) Sentinel-25D radioisotopic thermoelectric generator, were put into service in the Gulf of Mexico. Updating the design of the electronics equipment on the buoys permitted the use of the smaller power sources.

The Naval Undersea Research and Development Center has three operating RPG programs. The Oceanographic Telemetry Data System, which has been powered by a 25-W(e) RPG atop Fairway Rock in the Bering Strait since August 1966, operates underwater oceanographic sensors measuring salinity, water speed, current direction, temperature, and mass transport and transmits the data 15 miles to Cape Prince of Wales on the Alaskan mainland. A July 1970 inspection indicated that the power would be adequate for 2 additional years of operation. The Inter-Seamount Acoustic Range (ISAR) Experiment has been in operation in an undersea environment off the coast of California since June 1969. It consists of a bottom-mounted platform containing a 25-W(e) RPG, secondary batteries, electronic packages, and a series of transducers, all held in a vertical position by buoyant floats. It was designed for an unattended mission life of 3 years. The Radioisotope Powered Wave Study Transducer System, implanted June 21, 1971, in waters off San Diego, was designed to operate for 2 years, with relocation every 4 months, to support internal wave studies. The system contains a 25-W(e) source (Fig. 4) to power a transducer system, and a 100-mW(e) source to power a location hydrotherm beacon.

Fig. 4 Sentinel-25C3, 25W(e).

The Pacific Missile Range, Point Mugu, Calif., also has two RPG programs in operation. The first consists of three bottom-mounted deep-ocean transponders powered by 1-W(e) RPGs. These units, located in the Pacific Ocean near Midway Island, provide precise positioning data. They were implanted in October 1970 and are expected to operate for at least 10 years. The second unit, a portable automatic weather station powered by an 8-W(e) RPG (Fig. 5), became operational in November 1970. It is located on a small island with extremely rugged terrain off the California coast where highly reliable continuous operation is required.

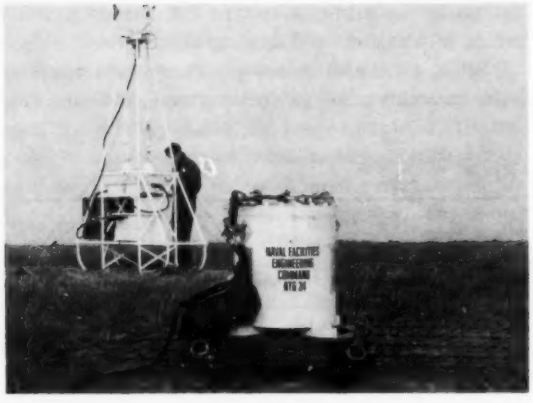


Fig. 5 Sentinel-8 8-W(e) RPG and weather station just after placement on the landing matting adjacent to the weather station.

LICENSE AND SAFETY REQUIREMENTS

Before an RPG can be authorized for a Navy operation, five approvals must be granted to ensure safe use. First, the manufacturer obtains an AEC license and a Department of Transportation (DOT) permit to construct and ship the RPG. Second, NAVFAC obtains AEC approval to add that model RPG to the Navy broad license. Third, the user is approved by NAVFAC to receive, store, assemble, and test the RPG under NAVFAC's broad license. Fourth, NAVFAC approves the particular operation to proceed under NAVFAC's broad license. And fifth, NAVFAC obtains DOT approval for shipment.

To obtain approval, the user sends a "Request for Safety Review," with an enclosed safety analysis (usually prepared with the assistance of NAVNUPWRU), to NAVFAC. The safety analysis required to receive an RPG is relatively simple and includes identification of the RPG, its storage locations, routes to be followed in transport, description of security and health-physics controls to be used, and a listing of personnel qualifications. The most comprehensive safety analysis is required for RPGs installed in floating buoys anchored in the ocean, where safety must be maintained even if the anchor should fail and the buoy float away. This means that communications with the buoy must be provided so that a straying RPG can be located and recovered before it floats into uncontrolled inhabited areas. Engineering analysis is required to show that the probability of the RPG's leaving its locations is minimal. Other contingencies involving loss or damage to the RPG are also analyzed and evaluated.

Although RPG-handling controls are important, the primary safety consideration for licensing is incorporated in the specification for RPG manufacture. The fuel capsule itself provides the primary safety barrier by its capability to contain the fuel under the most adverse conditions for the life of the fuel and is designed to contain the fuel until it has degraded to less than 1 Ci even when the capsule is exposed to seawater corrosion at depths down to 20 thousand ft. It also must resist maximum credible fire and shock exposure without rupture.

The biological shielding and housing provide additional safety control for containment and radiation, the housing being specified to meet operational as well as safety requirements—operation in ambient air from −40 to +120°F, in ambient water from 28 to 88°F, and in salt-air atmosphere with a relative humidity varying from 0 to 100%. The external operating pressure is specified at 500 psi for terrestrial and shallow-depth subsurface applications and 10,000 psi for deep-sea application. Occasionally, intermediate pressures are specified for special applications. Size and weight limits are also specified for RPGs to be installed in buoys.

The Navy RPGs ranging in power from 50 mW(e) to 25 W(e) are listed in Table 1. The deep-sea units have an operational depth limit of 20 thousand ft. The Sentinel-25C1 and the TRACS-25A are designed to operate at 13 thousand ft and the other units for operation at ocean depths to a thousand feet. The Sentinel-25Fs are 25-W(e) units that will weigh less than 15 hundred lb. They were delivered by Teledyne Corporation June 28, 1971. The URIPS units, with an output of 8 W(e), are to be supplied by Aerojet General Nucleonics. The Sentinel-25E units are 25-W(e) deep-sea units that were scheduled for delivery in August 1971.

COSTS

RPG prices vary according to the specifications for materials, construction, and quality control. Prices quoted by Teledyne Isotopes in 1969 were

Power output, W	Price, dollars
3	43,005
8	45,500
25	63,700
50	116,000
65	112,082

These prices were for orders of two or more units and did not include shipping containers, slings, or power conditioning equipment. Recent 25-W(e) RPGs procured by the Navy have cost from $70 thousand to $76 thousand in quantities of four or five, including certain extras, such as slings and shorting cables.

RPGs are useful in low-power missions requiring high reliability for extended times and are cost

Table 1 Navy RPGs

Name	Power, W(e)	Size, in.		Weight, lb	Initial power		Last power recorded	
		Dia.	Length		W(e)	Date	W(e)	Date
*SNAP-7C	10	19	21	3400	10	8-61	4.4	12-67
SNAP-7D	60	12	34	5000	71	6-62	42.7	5-69
†SNAP-7E	6.5	32	64	8000	6.4	6-62	3.9	12-70
†SNAP-21 SIOP 1	10	16	35	600				
†SNAP-21 SIOP 2	10	16	35	600	14.0	1-69	13.1	7-70
†SNAP-21 SIOP 3	10	16	35	600				
†SNAP-21 SIOP 4	10	16	35	600	14.4	5-69	13.8	7-70
†SNAP-21 SIOP 5	10	16	35	600				
†SNAP-21 SIOP 6	10	16	35	600				
*RIPPLE III	0.7	10	24	606	0.73	4-67	0.56	11-70
LCG-25A	25	30	35	3000	26.4	7-66	21.0	6-69
MW-3000A	3	34	25	2800	2.63	2-67	2.2	3-71
URIPS-P1-1002	1	14	19	835	1.21	10-61	0.99	3-71
MilliTRACS-101A	0.1	7	14	166	0.072	8-68		
URIPS-P1-1001A	1	14	19	845	1.45	6-68	1.21	3-70
Sentinel-25C1	25	27	28	2000	38.3	8-68	37.25	3-69
TRACS-25A	25	24	42	1470	20.2	11-68	7.2	1-71
Sentinel-25D	25	26	27	3000	41.1	8-69	37.5	6-70
Sentinel-25D	25	26	27	3000	37.0	8-67	34.5	6-70
Sentinel-25D	25	26	27	3000	41.7	8-69	35.5	6-70
*†Sentinel-25E	25	28	36	4000	40.5	3-69	38.3	6-70
*†Sentinel-25E	25	28	36	4000	40.3	3-69	35.0	6-70
*†Sentinel-25E	25	28	36	4000	40.0	3-69	37.8	6-70
Sentinel-25C3	25	20	27	1360	39.2	2-70	37.8	4-70
†URIPS-P1	1	14	20	800	1.66	3-70	1.66	3-70
†URIPS-P1	1	14	20	800	1.68	3-70	1.68	3-70
†URIPS-P1	1	14	20	800	1.73	3-70	0.2	11-70
†URIPS-P1	1	14	20	800	1.63	3-70	1.68	3-70
Sentinel-25F	25	23	27	1400	41.4	2-71	41.4	2-71
Sentinel-25F	25	23	27	1400	38.9	2-71	38.9	2-71
Sentinel-25F	25	23	27	1400	39.7	2-71	39.7	2-71
Sentinel-25F	25	23	27	1400	39.7	2-71	39.7	2-71
Sentinel-25F	25	23	27	1400	38.7	2-71	38.7	2-71
Sentinel-8	8	24	25	3150	12.1	1-70	12.1	1-70
URIPS-8	8	18	18	1500				
URIPS-8	8	18	18	1500				
URIPS-8	8	18	18	1500				
URIPS-8	8	18	18	1500				
†Sentinel-25E	25	28	36	4000				
†Sentinel-25E	25	28	36	4000				
†Sentinel-25E	25	28	36	4000				
†Sentinel-25E	25	28	36	4000				

*No longer in program.
†Deep-sea units.

effective for remote locations—any place where resupplying of fuel or recharging of batteries is either impossible or very expensive—requiring long-life application, i.e, unattended life exceeding that provided by primary batteries. For example, RPGs are generally economical for undersea power applications requiring 1 thousand to 10 thousand W(e) for longer than 1 year. Providing of batteries or fueled power systems undersea for longer than a year usually entails greater expense than the initial RPG cost. For milliwatt power applications, the choice between batteries and RPGs depends on the power level and the mission time. RPGs are generally economical for missions requiring higher power for longer times and for remote land or ocean surface applications where working time is limited by environmental factors—low temperatures, snow, rain, wind, or high seas.

FUTURE NAVY REQUIREMENTS

The Navy will require RPG power for anticipated application on ocean bottoms at depths to 20 thousand ft, in floating ocean subsurface installations, on ocean surfaces, and on remote land areas. At present it is anticipated that RPGs will be designed for either 20-thousand-ft depths or for surface and subsurface depths to a thousand feet. However, specifications can be written for more specialized application if the need arises. The AEC has been requested to develop RPGs in the 2- to 10-kW(e) power range, and it is anticipated that industry can produce 100-W(e) units by extending present technology without further development. A substantial portion of Navy RPG procurements in the near future is expected to be for prototype units in the higher power ranges. Potential applications include power requirements for ASW (*A*nti*S*ubmarine *W*arfare) surveillance and ordnance, oceanographic data collection, underwater navigation, electronic sentinel, weather data, and underwater life support, with power outputs ranging from 50 mW(e) to 5 kW(e).

Predicting Navy RPG requirements accurately is extremely difficult since Navy funding has a major impact on both the supply and demand of RPGs. However, the best estimates available in a nebulous area, where numbers depend on realization of Navy requirements and RPG production capability, indicate an inventory (including those under contract) of 41 units by the end of 1971, increasing to 44 in 1972, to 71 in 1975, and to 1700 in 1990 (Fig. 6). On the basis

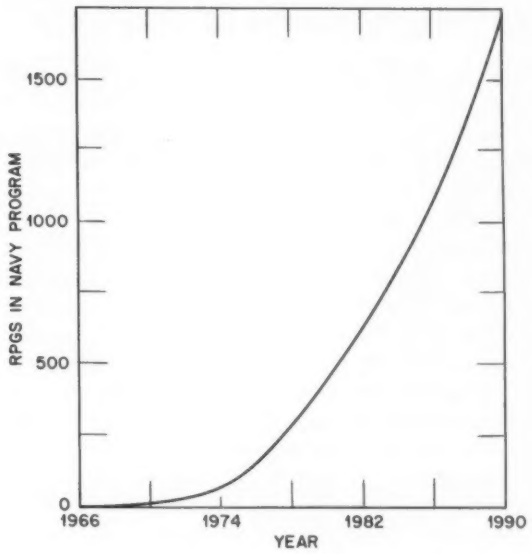


Fig. 6 Predicted Navy RPG requirements.

of several large potential programs now in the evaluation stage, these estimates are thought to be reasonable. They are updated from published data and were derived from information gained from field contacts. (MG)

Status of U. S. Radioisotopic Space Power Systems*

By R. T. Carpenter†

Supplementary Keywords: *energy source; thermoelectric system; ^{90}Sr; ^{244}Cm.*

Abstract: *Radioisotopic thermoelectric generators developed by U. S. government agencies to power automatic instrumentation in space studies are discussed.*

Nuclear power systems are attractive for use in space under a number of conditions—e.g., in the absence of sunlight; when there are high radiation fields, extreme temperatures, or dense meteorite fields; when high power level and long life are needed; and when heat is required in the payload. Radioisotopic sources are preferred over reactor sources when low powers are needed, the heat produced in radioisotope decay being converted to electricity. The heat may be used directly in some cases. For higher power levels, reactor sources may be preferred. This article is limited to a discussion of nonpropulsive radioisotopic thermoelectric generators (RTGs) for use both in space and on Earth and is concerned only with U. S. developments. Some basic information on isotopic SNAP (*S*ystems for *N*uclear *A*uxiliary *P*ower) units and on various other U. S. government- and industry-developed radioisotopic power sources is tabulated in an appendix to this article. Information on about 35 U. S. and about 30 non-U. S. sources is listed in a compilation completed in early 1970; a number of the sources have been described in *Isotopes and Radiation Technology*.

SYSTEMS IN USE

All U. S. power systems launched to date have used Pb–Te thermoelectric converters and ^{238}Pu heat sources. Plutonium-238 was selected for space use primarily because of its long half-life (87.5 years) and its low level of radiation emission. As larger heat sources were used, the philosophy of aerospace nuclear safety changed from one of presumed burnup in the atmosphere to one of intact reentry, which forced an evolution of fuel forms and heat-source designs. Plutonium metal was used in SNAP-3A and -9A; PuO_2 microspheres were used in SNAP-19 and -27. The oxide emits more neutrons than does the metal, but it also has a higher melt temperature, offers a lower inhalation hazard, and is a less soluble and less reactive fuel. All the isotopic units that have been successfully launched are still operating.

The first use of nuclear power in space was the SNAP-3A, launched on the Transit 4A Navy navigation satellite in June 1961 (and still operating). This 5-lb, 2.7-W(e) unit paved the way for a series of radioisotopic power systems launched in the subsequent decade. In all these systems, about 5% of the heat generated in a central heat source is converted to electricity as it passes through the static thermocouples; the rest of the heat is radiated away into space. The two SNAP-19s on the Nimbus III weather satellite are still supplementing the main solar cell–battery power system. The SNAP-27s left on the moon to provide the total power to the Apollo Lunar Surface Experiments Packages in the Apollo-12, -14, and -15 flights are still working very well. Because the first SNAP-27-powered station lasted well beyond its design life of 1 year, we are now getting the added benefits of three simultaneous stations on the moon.

The external emissions from SNAP-19 and -27 are neutrons from spontaneous fission and from the alpha–neutron reactions with the light elements in the fuel—oxygen and impurities—and gamma rays. Measurements made on SNAP-27 after about 2 years show a factor-of-2 increase in gammas, which is due to a buildup of such gamma-emitting products as ^{208}Tl, and may show a factor-of-7 or -8 increase after 15 to 20 years.

SYSTEMS UNDER DEVELOPMENT

Three near-term missions for which RTGs are being developed are a navigational satellite (Transit), a Jupiter flyby (Pioneer), and a Mars soft lander (Viking) (Table 1). The primary reasons for using RTGs on these missions are:

Transit: long life and resistance to radiation levels expected at this orbital altitude.

*From a paper presented at the National Symposium on Natural and Manmade Radiation in Space, Mar. 1–5, 1971, Las Vegas, Nev.

†AEC–NASA Space Nuclear Systems Office, Washington, D. C. 20545.

Pioneer: independence of solar flux and resistance to radiation to be encountered on the way to Jupiter.

Viking: independence of the environment on the surface of Mars.

Fueled ground test units and flight systems have been built for Transit and Pioneer.

The Transit RTG (Fig. 1*a*) is 24 in. in diameter and about 18 in. high. It is to be mounted directly on the satellite and provide up to 100 W(t) to help maintain fairly constant temperatures in the payload electronics as the satellite passes into and out of Earth's shadow. The electrical output will be 37 W initially and 30 W after 5 years. Heat is radiated from the source to the lightweight Pb–Te panels, which operate between 752 and 288°F. The total weight, including the mounting cone, is about 30 lb. The heat source (Fig. 1*b*), which is designed to contain the fuel during reentry and impact, weighs about 14 lb. The fuel—850 W(t) of ^{238}Pu as a PuO_2–Mo cermet—is contained in layers of refractory and noble metals surrounded by graphite for protection from reentry heating. The assembly is canned in a thin superalloy to prevent deterioration of the materials in the heat source while exposed to air before launch and to maintain a backpressure of gas in the gaps to minimize operating temperatures in space.

The Pioneer RTG is a modified SNAP-19 (Fig. 2). It is 15.8 in. across the fins, 11.1 in. high, and weighs 29.2 lb. It is fueled with 645 W(t) of $^{238}PuO_2$–Mo cermet and produces 38 W initially and 30 W after 3 years, i.e., at Jupiter encounter. The thermoelectric converter uses TAGS (Te, Sb, Ge, Ag) and Pb–Te materials operating between 950 and 350°F. The RTG is filled with a cover gas and welded shut. The heat source, which weighs 11.1 lb, is made of almost identical materials as that for the Transit. The reentry protection design is somewhat different because of the size constraints of the SNAP-19 heat source (3.5 in. across the flats of the hexagonal cross section, by 6.75 in. long) and the more severe heating environments of possible Pioneer mission aborts, which could lead to superorbital reentry. Since the generator is sealed, no can is used around the heat source.

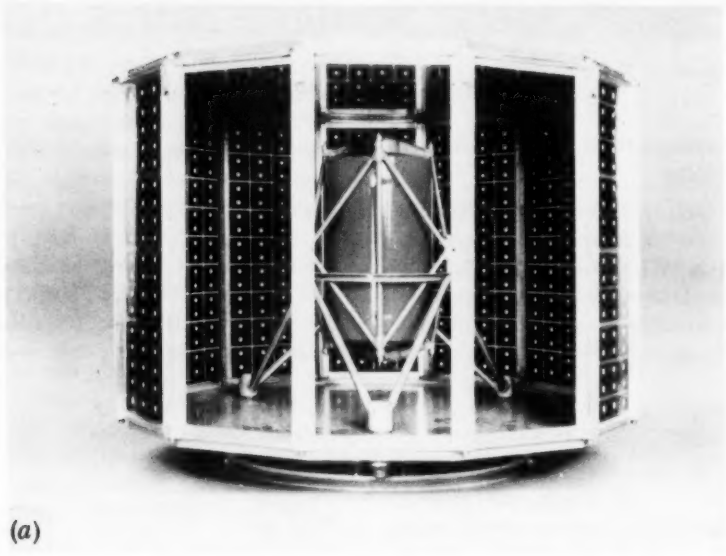
The generators to be used on the Viking (Fig. 3) are similar to those for the Pioneer. The fuel loading will be 675 W(t) to give 35 W(e) after 2 years, and the thermal design (fin length and housing thickness) will be tailored to the Viking mission environment.

Table 1 RTGs Under Development for Specific Missions

Mission	Power supply	Agency	Launch schedule	Power requirement, W(e)	Lifetime, years
Transit, navigational satellite	Transit RTG	Navy (DOD)	Classified	30	5
Pioneer, Jupiter flyby	4 SNAP-19s, modified	NASA	1972, 1973	120	3
Viking, Mars soft lander	2 SNAP-19s, modified	NASA	1975	70	2

For higher powered applications—e.g., for the LES spacecraft for space communication and for the Grand Tour missions to three outer planets—the multihundred-watt (MHW) modular RTG is being developed (Table 2). The outer-planet missions will require 10 times as much power, and mission lifetimes will be up to twice as long as any other mission to date. Size and weight constraints are very tight.

The MHW RTG (Fig. 4) will produce at least 145 W(e) initially from 2200 W(t) of $^{238}PuO_2$–Mo cermet. It is 11 in. in diameter by about 21 in. high and weighs about 75 lb. The thermoelectric converter uses 80% Ge–Si Airvac thermocouples operating at 1832°F or higher in a beryllium housing, which is sealed for operation in air. Radiative coupling between the heat source and the thermocouples allows flexibility in heat-source design. The insulation is refractory metal foils with ceramic separators. The very high operating temperatures that will occur and the safety factors needed to withstand the environments of any launch vehicle and any mission and still remain intact after reentry and impact require an advanced heat-



(*a*)

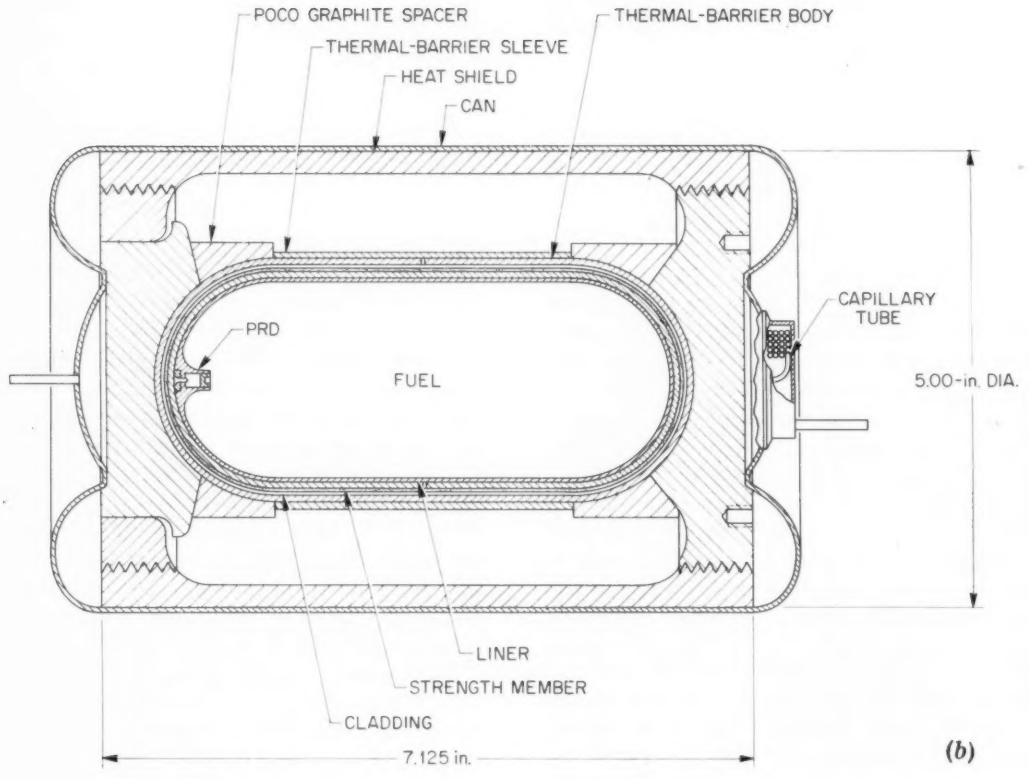


Fig. 1 (*a*) Transit RTG and (*b*) Transit heat source.

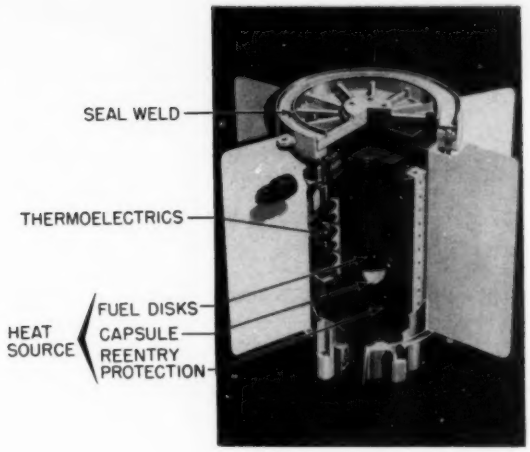


Fig. 2 Pioneer (modified SNAP-19) RTG.

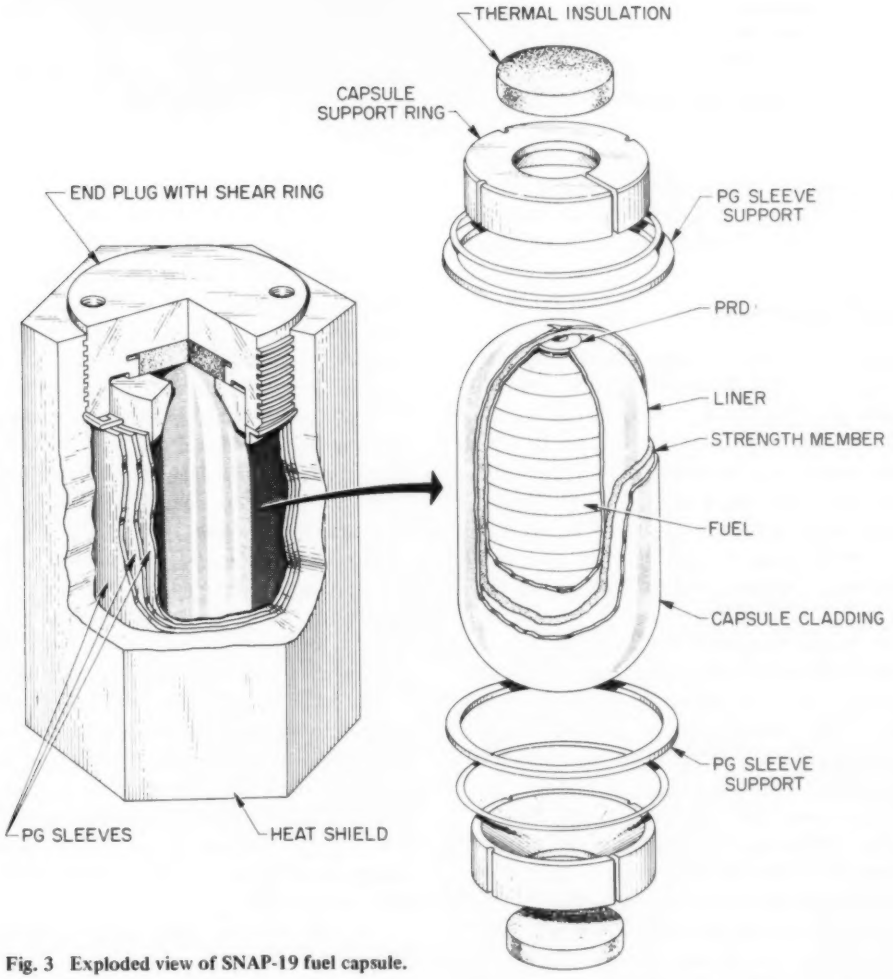


Fig. 3 Exploded view of SNAP-19 fuel capsule.

source design. One design being considered is 6.85 in. in diameter by 15.0 in. long, with a weight of more than 40 lb. It uses graphitic and ceramic materials and various shapes to bring the fuel through reentry and impact. This design was expected to be firmly established by late 1971. Pure PuO_2 is being considered as a replacement for the PuO_2–Mo cermet fuel. With 2200 W(t) (66 thousand Ci) of ^{238}Pu per module, the Grand Tour spacecraft will require an inventory of 8800 W(t) (264 thousand Ci) of ^{238}Pu—a neutron source of about 1.6×10^8 n/sec to be reckoned with.

Table 2 Multihundred-Watt RTG Applications

Mission	Power supply	Agency	Launch schedule	Power requirement, W(e)	Lifetime, years
LES,* space communication	2 MHW RTGs	Air Force (DOD)	Mid-1970s	220–300	5
Grand Tour, unmanned outer-space exploration	4 MHW RTGs	NASA	1976, 1977, 1979	300–550	>9

*Lincoln Laboratory's Experimental Satellite.

FUTURE DEVELOPMENTS

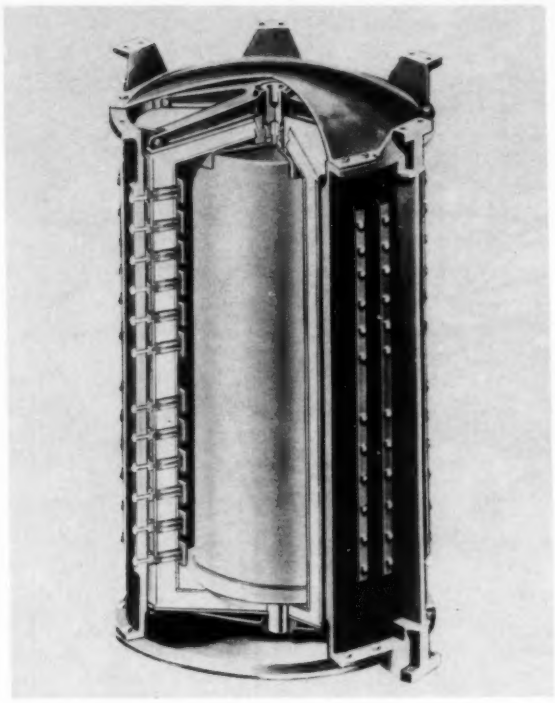
Improvements in these systems can be projected for future systems. The MHW Si–Ge RTG can be cascaded with the Pb–Te or TAGS thermoelectric panels similar to those used on the Transit RTG to provide higher power, a wider useful power range, and more efficient use of the fuel, leading to lower cost and lower radiation levels per electrical watt. This cascaded RTG (Fig. 5) would produce more than 200 W(e) at 9 to 10% efficiency, or more than 2 W(e)/lb with the same ^{238}Pu heat source as now in use.

If ^{244}Cm, another long-lived alpha emitter, should be used in the MHW, the power/weight ratio would be increased 10 to 15%. Curium-244 has a higher power density than ^{238}Pu because of its shorter half-life (about 18 years) and a promise of about one-fifth the cost per thermal watt. The penalty with ^{244}Cm is the higher neutron count due to spontaneous fission (approximately 1000 times that of ^{238}Pu). This could prevent the use of ^{244}Cm-fueled systems on radiation-sensitive scientific payloads and manned missions.

For power levels greater than that which is practical with the MHW, i.e., greater than 1 kW, more efficient power-conversion technologies are being considered—the static thermionic system and the dynamic Brayton system. Design studies have been completed on a 110-W(e) ^{244}Cm-fueled thermionic module, which was an outgrowth of the SNAP-13 thermionic generator development completed in 1965. These studies show that thermionic modules in the 200- to 500-W(e) range offer a module efficiency about twice that of thermoelectric generators and a specific power of about 4 W(e)/lb—also about twice that obtained with thermoelectric generators. Thermionic generators are also smaller in size because of their high radiator temperature and thus are attractive for missions close to the sun or on the surface of the inner planets, where ambient temperatures are very high. To achieve these advantages, the high-power-density ^{244}Cm fuel must be used and heat-source operating temperatures must be in excess of 3000°F. Much more development work must be done on isotopic thermionic generators to demonstrate their operating performance and lifetimes.

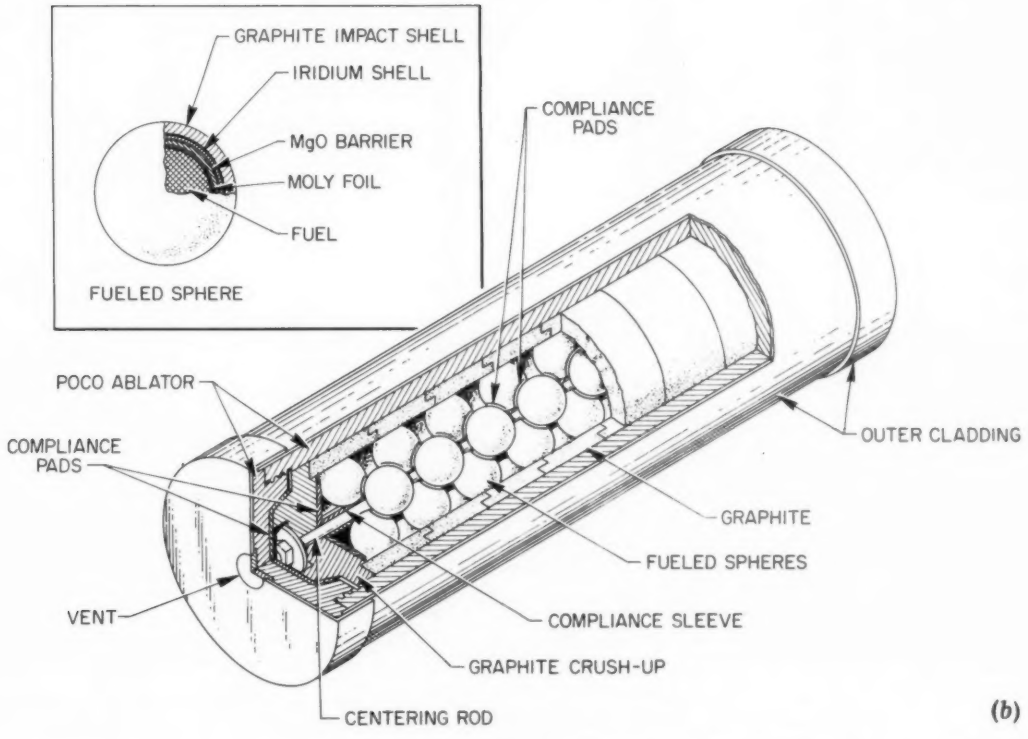
The use of the dynamic Brayton cycle, which has been under development at NASA's Lewis Research Center for several years, allows efficiencies as high as 28% at heat-source temperatures comparable to those for the MHW in the power range 2 to 10 kW. It can use ^{238}Pu or ^{244}Cm. The Brayton conversion machinery, an electrically heated system (minus the radiator), has been tested for more than 2500 hr, and the combined rotating unit is still undergoing a life test after some 5000 hr, most of which has been unattended. A joint NASA–AEC program is under way to conduct an isotope-heated test of the system under simulated space conditions.

In the isotopic heat-source assembly for the Brayton system, an array of heat sources is carried in a



(*a*)

Fig. 4 (*a*) MHW RTG and (*b*) MHW reference heat-source design.



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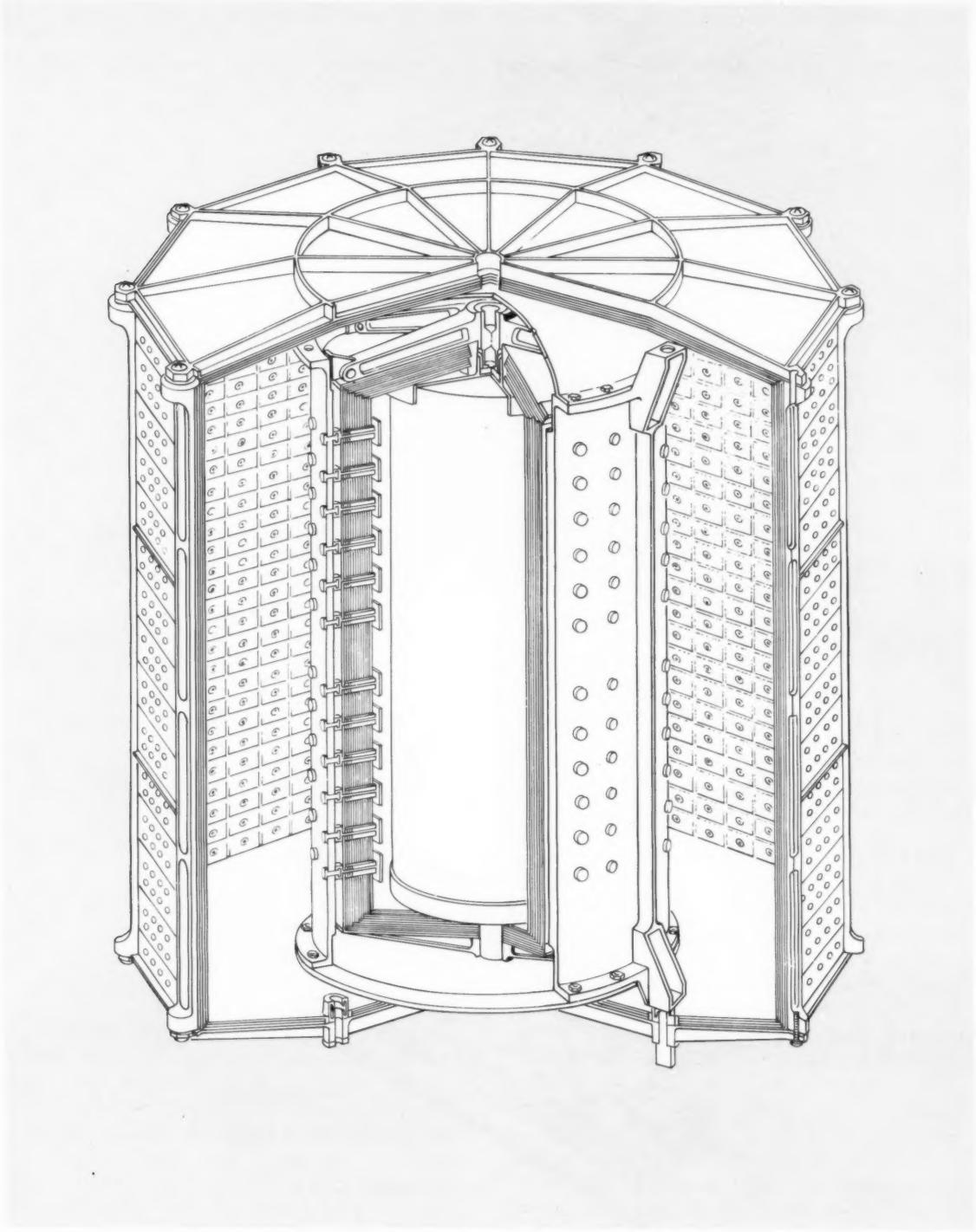

Fig. 5 Dual stage MHW-RTG sealed design.

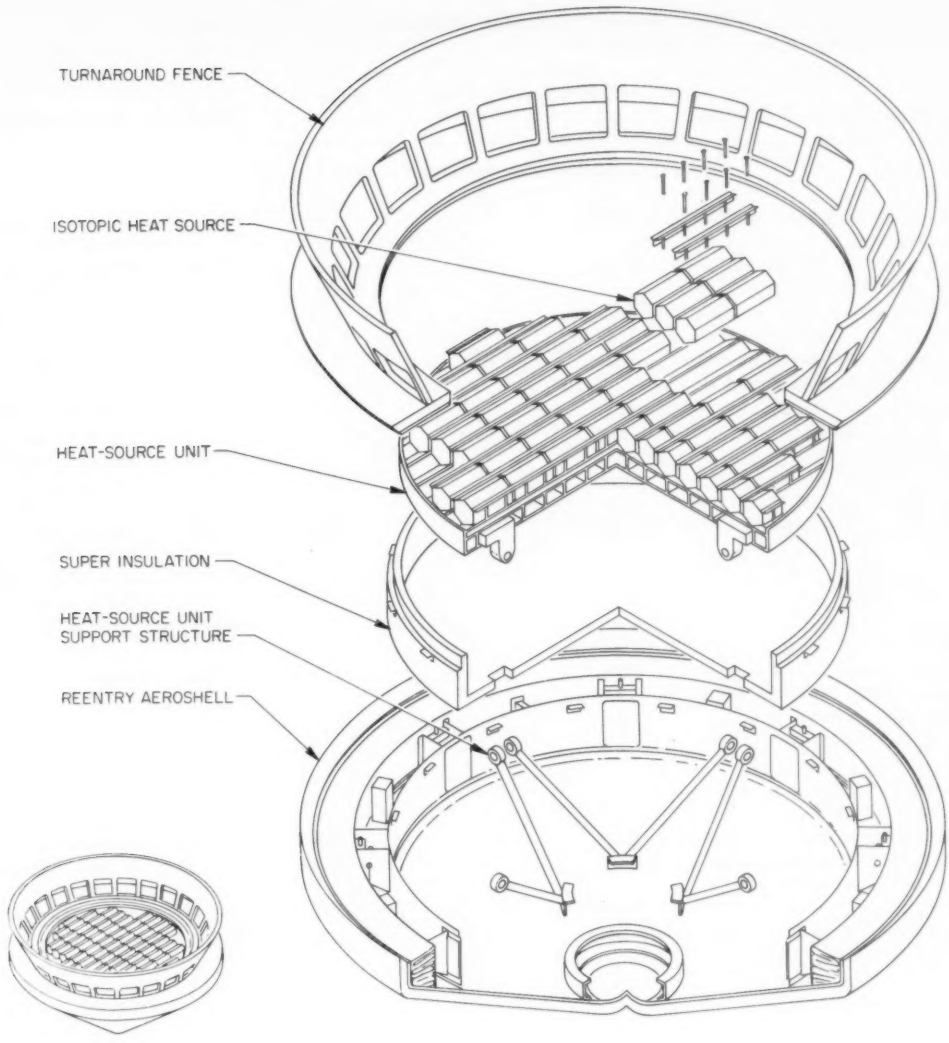

Fig. 6 Heat-source reentry vehicle assembly for the Brayton cycle unit.

reentry vehicle (Fig. 6), which provides double protection during reentry mishaps and maximizes the chances of recovery of the large isotope inventory. A 12.5-kW power system, which has been studied for use on the manned orbital space station, would contain 52.8 kW(t) (1.6 MCi) of ^{238}Pu at the beginning of life. The reentry vehicle, including the isotopic heat sources, would be about 8 ft in diameter and would weigh about 3900 lb. The total 12.5-kW system would weigh about 6000 lb, or about 2 W(e)/lb. This system type is especially attractive for low-orbit, man-tended spacecraft which can be launched and recovered by the planned space shuttle. (MG)

APPENDIX

Besides the space radioisotopic electric generators mentioned above, a number of units have been developed by both U. S. government and industry for terrestrial and maritime use. All important electricity-producing units are listed in Table 3.

Table 3 Electric Generators Developed in the United States

Designation	Application	Electric power, W	Weight, lb	Design life	Fuel	Status in January 1971
		By U. S. Government for Space Use				
SNAP-1	Satellite (Air Force)	500	–	60 days	^{144}Ce	Replaced by longer-lived SNAP-1A in 1959
SNAP-1A	Satellite (Air Force)	125	200	1 year	^{144}Ce	Program canceled in 1959
SNAP-3	Thermoelectric demonstration device (AEC)	2.5	4	90 days	*^{210}Po	Shown to President Eisenhower in January 1959
SNAP-3A	Navigation satellite (Navy) (Transit 4A and 4B)	2.7	4.6	>1 year	*^{238}Pu	Units launched in June and November 1961; June unit still operating at reduced power level but voltage converter on November unit shorted out in June 1962
SNAP-9A	Navigation satellite (Navy/Transit 5BN)	25	27	>1 year	*^{238}Pu	Units launched in September and December 1963 and still operating at reduced power levels; third unit aborted during launch in April 1964
SNAP-11	Surveyor lunar lander (NASA)	25	30	90 days	*^{242}Cm	Surveyor requirement canceled 1965; electrically heated unit delivered to NASA and on life test since 1966; fueled demonstration at ORNL in July 1966
SNAP-13	Thermionic demonstration device (AEC)	12.5	4	90 days	*^{242}Cm	Fueled demonstration at ORNL in November 1965; program completed in 1966
SNAP-17A and 17B	Communication satellite (Air Force)	30	30	>1 year	^{90}Sr	Design and component test phase completed November 1965 (SNAP-17A thermoelectric modules still on life tests)
SNAP-19A	Imp satellite (NASA)	20	18	>1 year	^{238}Pu	Design and component tests completed in 1963; used on Imp because of radiation interference with payload instrumentation
	Various satellites (AEC)	250	–	>1 year	^{90}Sr	Six different design studies completed in 1964
	Surveyor lunar roving vehicle (NASA)	40	22	1 year	^{238}Pu	Design and integration study completed in 1964
	Extended Apollo missions (AEC)	1500	–	30–90 days	^{210}Po	Design and feasibility studies completed in 1964

*Units fueled.

Table 3 (Continued)

Designation	Application	Electric power, W	Weight, lb	Design life	Fuel	Status in January 1971
			By U. S. Government for Space Use (Continued)			
SNAP-19B-1, -2, -3	Meteorological satellite (NASA) (Nimbus III)	30	30	>1 year	*^{238}Pu	First Nimbus launch aborted in 1968 and fuel recovered from offshore waters; replacement units, launched in April 1969, operating continuously at gradually decreasing power level; electrically heated units on life tests at NASA laboratories
SNAP-25	Various satellites (AEC)	75	35	>1 year	^{238}Pu	Program canceled
SNAP-27	Apollo Lunar Surface Experiment Packages (NASA)	63.5	68 (includes 24.5 cask)	1 year	*^{238}Pu	First unit placed on lunar surface by Apollo 12 astronaut in November 1969 and has continuously powered ALSEP; electrically heated units on life test at NASA laboratories; second unit landed in deep Pacific Ocean on Apollo 13 abort. Additional units planned for use on Apollos 14 to 17
SNAP-29	Various satellite and lunar missions (DOD and NASA)	400–500	400–500	90 days	^{210}Po	Program canceled in 1969 with completion of component tests
	Various missions (DOD and NASA)	250	–	5 years	^{238}Pu ^{90}Sr	Three design studies completed in 1967; controlled intact reentry and ground handling included
	Thermionic module development (AEC)	100	20	–	^{244}Cm	Program suspended after completion of preliminary design in 1967 and component tests in 1970
	Isotope Brayton ground test (AEC and NASA)	3000–15,000	–	>1 year	^{238}Pu	Preliminary heat-source designs completed in 1966; fuel capsule development 1967–1970; NASA completed 2500-hr life test on electrically heated system in 1970; fueled ground test planned for 1973

(Table continues on the next page.)

Table 3 (Continued)

Designation	Application	Electric power, W	Weight, lb	Design life	Fuel	Status in January 1971
		By U. S. Government for Space Use (Continued)				
Transit RTG	Navigation satellite (Navy) improved Transit	30	30	5 years	^{238}Pu	Electrically heated generator completed in 1970; fueled qualification unit and flight unit planned for 1971
Pioneer RTG	Pioneer F and G (Jupiter flyby) (NASA)	30	30	3 years	^{238}Pu	Electrically heated system (four generators) delivered to NASA in 1970; fueled prototype system to be delivered in 1971; Pioneer F launch scheduled for 1972; Pioneer G for 1973
Viking RTG	Viking Mars lander (NASA)	35	30	>2 years	^{238}Pu	Electrically heated system (two generators) to be delivered to NASA in 1971; two missions scheduled for 1975
Multi-hundred-watt RTG	Various missions (DOD and NASA)	100–200	–	5–10 years	^{238}Pu	Preliminary design completed in 1970; electrically heated tests in 1971; fueled prototype in 1972
		By U. S. Government for Terrestrial and Marine Use				
Sentry	Arctic weather station–Axel Heiberg (Weather Bureau)	5	1680	2 years	$*^{90}Sr$	Successfully powered weather station from August 1961 to August 1964; defueled in 1969
SNAP-7A	Navigation buoy (Coast Guard)	10	1870	2–5 years	$*^{90}Sr$	Installed december 1961; power degradation caused refurbishment in 1963; reinstalled January 1964; removed from buoy in 1967 for disassembly and inspection
SNAP-7B	Lighthouse (Coast Guard) offshore oil platform (Phillips)	60	4600	2–5 years	$*^{90}Sr$	Installed in Baltimore Lighthouse in May 1964 and performed perfectly for 2 years; relocated to oil platform in Gulf of Mexico in August 1966 and successfully operated navigation aids until returned to ORNL in 1969

Table 3 (Continued)

Designation	Application	Electric power, W	Weight, lb	Design life	Fuel	Status in January 1971
		By U. S. Government for Terrestrial and Marine Use (Continued)				
SNAP-7C	Antarctic weather station (Navy)	10	1870	2–5 years	^{*90}Sr	Installed in February 1962; intermittent operation of station due to weather equipment problems until 1968; returned to ORNL in 1969
SNAP-7D	Floating weather station (Navy)	60	4600	2–5 years	^{*90}Sr	Installed in January 1964 in Gulf of Mexico and operated successfully with periodic repairs to auxiliary equipment; in storage awaiting redeployment since 1969
SNAP-7E	Ocean-bottom beacon (Navy)	6.5	6000	2–5 years	^{*90}Sr	Installed off coast of Bermuda in July 1964 and signals ceased November 1968; unit recovered from ocean floor in November 1969 was still producing 4.4 W; returned to ORNL in March 1970 and shipped to Naval Avionics Facility in Indianapolis
SNAP-7F	Offshore oil platform (Phillips)	60	4600	2–5 years	^{*90}Sr	Completed 1-year fueled operation in October 1965, 4 months of which were on oil platform in Gulf of Mexico; sharp drop in power, and unit disassembled and replaced by SNAP-7B
	Demonstration device for deep sea (AEC)	5	500	>1 year	^{137}Cs	Initiated in 1960 but terminated after completion of preliminary design and component tests in 1962
	Demonstration device (AEC)	5–10	–	>1 year	Mixed fission products	Terminated after electrically heated tests in 1963
SNAP-15A	Nuclear weapons (AEC)	0.001	1	4 years	^{*238}Pu	Initiated March 1963; fueled and put on life tests in 1964; fueled units continue on test
SNAP-15B	Nuclear weapons (AEC)	0.001	1	4 years	^{*238}Pu	Initiated March 1963; terminated in favor of SNAP-15A in July 1964

(Table continues on the next page.)

Table 3 (Continued)

Designation	Application	Electric power, W	Weight, lb	Design life	Fuel	Status in January 1971
By U. S. Government for Terrestrial and Marine Use (Continued)						
SNAP-15C	Communications demonstration device (AEC)	0.1	–	–	*^{238}Pu	Initiated July 1963; fueled generator on test in June 1965; additional units tested through termination of program in 1969
SNAP-19C	Remote telemetry station (Navy)	30	40	>1 year	*^{238}Pu	Program completed in 1966
SNAP-21A	Various deep-sea uses	10	500	5 years	^{90}Sr	Completed design and component testing in 1965; terminated in favor of SNAP-21B
SNAP-21B	Various deep-sea uses	10	650	5 years	*^{90}Sr	Completed design and component testing in 1965; first of four units fueled in December 1968; two units still under ocean environment tests and two units delivered to Navy in June 1970 for use off Bermuda
SNAP-23A	Various terrestrial uses	60	1100	10 years	*^{90}Sr	Design and component testing in 1964–1967; electrically heated in 1968 and 1969; fueled in February 1970 and unit on life tests
	Various terrestrial uses	0.1–1.0	–	2–5 years	^{238}Pu ^{90}Sr ^{147}Pm	Design studies completed in June 1966
	Heart pacemaker (AEC–NIH)	0.000162	<1	10 years	*^{238}Pu	Initiated July 1966; electrically heated tests in 1967; fueled units tested in 1968 and implanted in dogs in 1969
	Deep-ocean uses	2000–10,000	–	2–5 years	^{90}Sr ^{60}Co	Preliminary design studies under way; use date ~1976
By U. S. Industry for Terrestrial and Marine Use						
LCG-25A/ Sentinel-25A (Teledyne-Isotopes)	Oceanographic instruments (Navy)	25	3000	5 years	*^{90}Sr	Installed in Bering Strait in August 1966; annual inspections performed and continues satisfactory operation
MW-3000A (Teledyne-Isotopes)	Deep-ocean program (Navy)	2.5	2800	5 years	*^{90}Sr	Delivered to Port Hueneme in February 1967; installed in underwater test in May 1967 and continues satisfactory operation

Table 3 (Continued)

Designation	Application	Electric power, W	Weight, lb	Design life	Fuel	Status in January 1971
			By U. S. Industry for Terrestrial and Marine Use (Continued)			
LCG-25B/ Sentinel-25B (Teledyne-Isotopes)	Ocean engineering program (Navy)	25	3000	5 years	^{*90}Sr	Installed in underwater test at Port Hueneme in June 1967; replaced thermoelectric module in January 1968 and returned to Martin Company in April 1968
URIPS PI-1002 (Aerojet-General)	Ocean engineering program and acoustic range program (Navy)	1	835	5 years	^{*90}Sr	Installed in underwater test at Port Hueneme in September 1967 and continues satisfactory operation
914E001 (Westinghouse)	Underwater test unit (Navy)	5	4800	10 years	^{90}Sr	Electrically heated unit put on test at Annapolis in June 1967; sent to Fort Belvoir training program in August 1968
STEP-1 (Sanders Nuclear)	Undersea demonstration device	0.1	90	6 months	^{*170}Tm	Fueled in August 1967
LCG-25Cl/ Sentinel-25C (Teledyne-Isotopes)	IRLS (Nimbus) buoy and acoustic range program (Navy)	25	2000	5 years	^{*90}Sr	Delivered in November 1967; returned to Martin Company in March 1968 and implanted in ocean off Puerto Rico in April 1968; buoy equipment failed in May 1968 and unit recovered and sent to Port Hueneme in September 1968; implanted at San Juan Seamount in June 1969 and continues satisfactory operation
URIPS PI-1001A (Aerojet-General)	Ocean engineering program and acoustic range program (Navy)	1	845	5 years	^{*90}Sr	Delivered to Port Hueneme in February 1968; in storage at San Diego since March 1969; continues satisfactory operation
Isomite A (Douglas Labs.)	Thermionic demonstration device	0.02	<1	2–5 years 10 years	^{*147}Pm ^{*238}Pu	First fueled in February 1968; several units on tests
Sentinel-3 (Teledyne-Isotopes)	Oil-well controls (Sinclair)	3	3000	5 years	^{*90}Sr	Two units installed in Gulf of Mexico in May 1968
Betacel (Douglas Labs.)	Pacemakers, chronometers	0.00005–0.00025	<1	5–8 years	^{*147}Pm	First four fueled in early 1968; large number of fueled units on tests
TRACS-25A (NUMEC)	Acoustic range program (Navy)	25	1470	3 years	^{*90}Sr	Delivered in January 1969; installed for 1 day at Andros Island in February 1969, then sent to storage; degradation in power caused replacement by Sentinel-25C3
Isomite B (Douglas Labs.)	Pacemaker	0.0002–0.0008	<1	10 years	^{*238}Pu	First fueled in March 1969; several on tests

(Table continues on the next page.)

Table 3 (Continued)

Designation	Application	Electric power, W	Weight, lb	Design life	Fuel	Status in January 1971
			By U. S. Industry for Terrestrial and Marine Use (Continued)			
Isomite C (Douglas Labs.)	Telemetry devices, biomedical uses	0.005–0.1	<1	10 years	^{*238}Pu	First fueled in September 1969; number of units on tests
Sentinel-25D (Teledyne-Isotopes)	NOMAD buoy (Navy)	25	3000	5 years	^{*90}Sr	Three units delivered in October 1969; installed in buoys in Gulf of Mexico June–August 1970 and continue satisfactory operation
Sentinel-25E (Teledyne-Isotopes)	Oceanographic instruments in Pacific Sea Spider buoy (Navy)	25	4000	5 years	^{*90}Sr	Three units delivered in March 1969 and unsuccessful installations attempted in August and October 1970; units sent to AEC in August 1970 for use in remote seismic stations off Amchitka, Alaska; 4 more units to be delivered to Navy in mid-1971
URIPS-P1 (Aerojet-General)	Deep-ocean transponders (Navy)	1	850	5 years	^{*90}Sr	Four units delivered in May 1970; 3 units installed at Midway Island in October 1970 but 1 returned to Aerojet in December 1970
MilliTRACS-100A and 101A (NUMEC)	Deep-ocean engineering program (Navy)	0.1	166	5 years	^{*90}Sr	Delivered to Port Hueneme in February 1968; returned to NUMEC in March 1968 for disassembly due to loss of power; replaced by MilliTRACS-101A in July 1970; in storage at San Diego since November 1970
Sentinel-8 (Teledyne-Isotopes)	Automatic weather station (Navy)	7	3150	5 years	^{*90}Sr	Delivered in March 1970; installed on San Miguel Island in November 1970
Sentinel-25C3 (Teledyne-Isotopes)	Cosmos stable platform (Navy)	25	1360	5 years	^{*90}Sr	Delivered in March 1970; installation attempt unsuccessful in August 1970 and sent to San Diego in November 1970; continues satisfactory operation
URIPS-8 (Aerojet-General)	Oceanographic instruments (Navy)	8	1500	5 years	^{90}Sr	Two units scheduled for delivery in February 1971; 2 more on order
Sentinel-25F (Teledyne-Isotopes)	Automatic weather station (Navy)	25	1400	5 years	^{90}Sr	Five units scheduled for delivery in January 1971
STEP-III (Sanders Nuclear)	Undersea demonstration device	25	1000	5 years	^{90}Sr	To be fueled February 1971

TRISTAN ^{90}Sr ENERGY SOURCE*

A prototype of the 24-W(e) TRISTAN radioisotope-powered thermoelectric generator, designed to supply power for automatic measuring equipment in deep-sea stations, has operated satisfactorily for more than 5 thousand hr. Developed over a 4-year period by Messerschmitt-Bölkow-Blohm GmbH and Siemens Aktiengesellschaft, and sponsored by the West German Ministry of Education and Science, the first active model was officially started up in a water tank at the Siemens research center in Erlangen on June 24, 1971.

The ^{90}Sr fuel, supplied by the French Atomic Energy Commission, generates 294 W(t) from 36 two-stage thermoelectric elements; the first stage is a Ge–Si unit at 900 to 250°C and the second, Bi–Te at 250 to 50°C. The 294 W(t) is converted to 22 W(e) at 24 V dc by a dc/dc converter. The fuel capsule is a single-wall superalloy with a helium atmosphere. The outer wall of the generator, an 84-cm-high by 11-cm-thick lead shield, decreases the radiation level at the surface to 40 mR/hr. The thermal insulation is pressed fiber in a low-temperature krypton atmosphere.

The corrosion-resistant housing of the generator is not crushed by 1000 atm pressure, allowing the generator to be dropped to depths of 10 thousand m. The 1400-kg generator offers a maintenance-free operating period of 5 to 10 years. (MG)

*Summary of TRISTAN Isotopic Generator for Terrestrial Use (in German) by P. Zahn and V. Merges, *Atomwirtschaft*, **15**: 142-145 (1970) plus Messerschmitt-Bölkow-Blohm press release and data sheet.

SYMPOSIUM ON THE MANAGEMENT OF RADIOACTIVE WASTES FROM FUEL REPROCESSING

Paris, France, Nov. 27–Dec. 1, 1972

The European Nuclear Energy Agency and the International Atomic Energy Agency are jointly sponsoring a symposium on the management of radioactive wastes. It will be held at OECD Headquarters, 2, rue André Pascal, Paris.

Topics to be covered include: sources of radioactive wastes, waste production and management, routine releases from reprocessing plants, storage of fission-product solutions, solidification processes for fission-product solutions, ultimate storage or disposal, decommissioning of waste-storage facilities and reprocessing plants, and economic aspects of waste management.

As a part of the symposium, technical visits will be arranged (at the participants' expense) to plants in France, Germany, and possibly other European countries. Participation will be limited to persons nominated by the government of a Member State of the ENEA, IAEA, or an international organization invited to participate.

For details about submission of papers to be presented, registration, accommodations, etc., persons outside the United States should write

ENEA/IAEA Symposium on the Management of
Radioactive Wastes from Fuel Reprocessing
c/o European Nuclear Energy Agency
38, Boulevard Suchet
F-75 Paris 16e, France

and persons in the United States should write

Mr. John H. Kane
Special Assistant for Conferences
U. S. Atomic Energy Commission
Washington, D. C. 20545

Section V

Isotopes and Radiation Technology

Applications in Life Sciences

Clover-Burr Uptake of Calcium*

By P. G. Ozannet and C. H. E. Werkhoven†

Supplementary Keywords: *agriculture; tracer; biochemistry.*

In Western Australia, where 9000 tons of subterranean clover seed is harvested annually, the production of healthy seed is of considerable importance. A good supply of calcium is important for setting of seed, but, in contrast to ^{35}S, calcium is not readily translocated into the developing seed. Since subterranean clover sets more seed when the burr is in contact with soil, the possibility that the burrs absorb calcium directly was investigated. The movement of ^{45}Ca-labeled calcium has been studied in citrus, apples, beans, peanuts, and in subterranean clover in the plant itself, but not in the subterranean clover seed.

For studying the uptake of calcium by the burr, subterranean clover was grown in loam, in pots, under favorable growing conditions. After 4.5 months, when the clover was in full flower, the florets were wrapped in absorbent cotton, placed in plastic vials, and one on each of 50 runners was moistened with a solution containing $^{45}CaCl_2$, 1 μCi/ml. Two months later, when the burrs were mature, they and the runners were harvested, oven dried, and weighed, and the ^{45}Ca was determined with a thin-end-window Geiger counter.

The results (Fig. 1), which are of interest to seed growers, showed clearly that not only can the burrs of subterranean clover absorb calcium but also that calcium can be translocated into the subtending leaf. Some translocation to leaves near the growing tip was evident, but that to other burrs or to the base of the plant was small. (MG)

*Summary of article in *Atomic Energy in Australia*, **14**(1): 16-18 (January 1971), 14 references.

†Western Australia Laboratories, C.S.I.R.O., Wembley, Western Australia; and Institute for Soil Fertility, Haren, Groningen, The Netherlands, respectively.

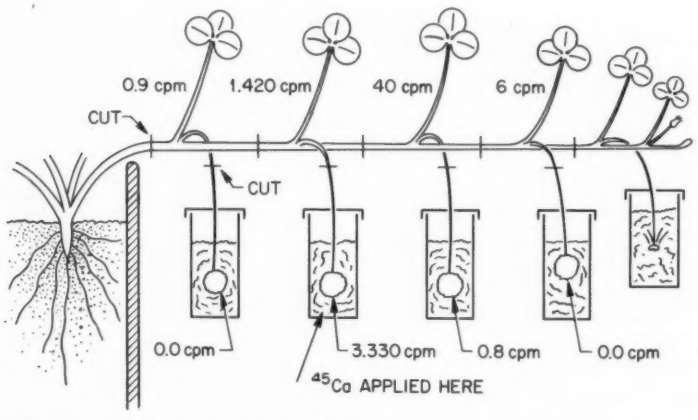

Fig 1 Experimental arrangement and location of ^{45}Ca 2 months after its application to a seed burr.

RADIOACTIVE METHYLMERCURY PROVES RESIN CAN PURGE MERCURY FROM BODY*

Supplementary Keywords: *biology; chemistry, organic; biochemistry; material tracing; sorption; pollution.*

Radioactive methylmercury has been used to prove that a synthetic resin can purge mercury from the bodies of mice. The resin, which contains a sulfhydryl group, was developed by the Dow Chemical Co. The study, done by Dr. T. W. Carlson and associates at the University of Rochester Medical Center, is a new approach to the environmental mercury problem—an approach that seeks to reduce the amount of mercury absorbed by the body and to increase the rate of excretion of the absorbed mercury. Food containing 1 wt. % of the resin was given to mice injected with radioactive methylmercury. Mice fed the resin excreted mercury two and a half times as fast as a control group fed normal food. Ability of the resin to prevent mercury absorption was shown by doctoring food with radioactive methylmercury and feeding it together with resin-containing food. Compared with a control group, the resin-fed mice absorbed less methylmercury. Carlson believes that, by the resin's combined effects of decreasing mercury absorption and increasing mercury excretion, methylmercury uptake from food can be decreased by 50%. The resin will be tested on humans if a group exposed to high levels of mercury can be found. (HPR)

*Abstract of article in *Industrial Research* for August 1971, p. 18.

SEMICONDUCTORS ENTER THE BEHAVIORAL SCIENCES*

Supplementary Keywords: *medicine; biology; biochemistry; material tracing; kinetics; blood; brain; instrument; semiconductor; data handling; unusual material.*

A unique solid-state detector has been designed to permit in vivo measurement of the uptake and turnover of ^{32}P and other beta-emitting radionuclides in experimental animals. The detector is a semiconductor device inserted through a cannula previously fixed, by surgery, in place over the point of interest. One section (2-mm diameter, 10-mm length) of the two-section probe houses a Si(Li) detector mounted in electroform nickel (≤ 2-μ wall thickness) and the other section (1-cm diameter, 1-cm length), a preamplifier. A cable, power supply, amplifier, and data-handling system complete the instrumentation. The light weight of the probe and the flexibility of the cable permit the animal to move normally.

This in situ measuring system has numerous advantages:

1. Live animals can be used to make simultaneously both psychological and physiological studies.
2. Sacrifice of animals is not required; therefore changes in metabolic turnover, especially in labile brain metabolites, are avoided.
3. The number of animals required per experiment is decreased and thus also is the amount of training and testing.
4. Repeated measurements can be made on the same animal, e.g., the rate of incorporation of phosphate in the brain under such different behavioral conditions as sleep, anesthesia, and learning.
5. Kinetic and turnover studies in the brain, blood, and other organs are possible.
6. The energy requirements of the brain can be estimated from ^{32}P uptake, together with data taken by means of other isotopes, e.g., ^{18}O.

The satisfactory performance of the device was demonstrated with two probes used to measure simultaneously the ^{32}P-uptake curves for the blood and brain of a rat injected with $Na_3{}^{32}PO_4$. The curve for the blood rises rapidly to a peak within 3 to 4 min as labeling occurs after $Na_3{}^{32}PO_4$ injection; the curve then reverses to level off as the $^{32}PO_4^{3+}$ is absorbed and metabolized. The curve for the brain shows a rise in the first 10 min as ^{32}P is transported by the blood to the region around the detector; the initial rise is followed by a rapid leveling off as the ^{32}P is incorporated into the brain. Additional experiments will be made with labeled compounds to relate phosphate uptake by the brain to different behavioral states. (HPR)

*Abstract of article by J. H. Ewins, S. S. Friedland, A. Mayevsky, and D. Samuel, Solid State Detectors in Behavioral Studies, *IEEE (Institute of Electric and Electronic Engineers), Transactions on Nuclear Science*, NS-17(3): 275-281 (1970).

MEASUREMENT OF GASTRIC EMPTYING USING THE SCINTILLATION CAMERA AND ^{129}Cs*

Gastric emptying was detected by observing, with an Anger camera, the disappearance from the stomach of the radiation from 100 μCi of ^{129}Cs–zirconium phosphate suspension ingested by the patient in a solid meal. Cesium-129 has a physical half-life of 32 hr, significant gamma radiation between 370 and 410 keV, and a half-value thickness in tissue of 9.3 cm. The test is useful in, for example, examining vagotomized patients.

*Abstract of article by T. Jones, J. C. Clark, N. Kocak, A. G. Cox, and H. I. Glass, *British Journal of Radiology*, **43**: 537-541 (1970).

Transpiration Measurement in Pines Using Tritiated Water as a Tracer

By J. R. Kline, C. F. Jordan, and R. C. Rose*

Supplementary Keywords: *biochemistry;* ^{3}H.

Abstract: *Tritiated water was used for field measurements of transpiration by red pines throughout a growing season. The method used is based on previously published theoretical analyses of tracer dynamics in steady-state flowing systems.*

Transpiration of water by plants has been measured in the field by various techniques, ranging in scale from the measurement of water flux in individual leaves or groups of leaves to the measurement of whole-watershed evaporation.[1,2] Methods based on individual plants include the cut-leaf, tent, and heat-pulse methods. These methods are often criticized because the experimental procedures may modify the actual evaporation rates. A proposed[3] modification of the cut-leaf method involves remote measurement of the black-body surface temperatures of leaves excised for weight-loss determination and of leaves still attached to the plant. While this method undoubtedly yields correct single-leaf evaporation rates, it is extremely difficult to convert such rates to whole-plant rates with precision. In what is essentially a modification[4] of the heat-pulse method, the water-flow rate in tree stems is determined with ^{32}P and the conducting cross section of the tree is estimated by microscopic examination, the transpiration rate given by the product of flow rate times cross section. The advantage of being able to obtain the water flow in a tree for short times is somewhat offset by the inaccuracy of the microscopic estimation.

Kline et al.[5] have suggested that the well-developed theory of tracer dynamics[6-9] in steady-state flowing systems could be utilized to determine mean transpiration rates by individual plants, using tritiated water as a tracer. The basic method involves injection of a known amount of tritiated water into the stems of trees and computing the transpiration rate from the measured activity of the plant at various times. The development of this basic method and demonstration of its use in the estimation of the seasonal water consumption of a uniform stand of young red pines (*Pinus resinosa*) near Argonne, Ill., are reported here. Advantages of the method over conventional watershed methods are that no site preparation or constraints are required, the forest need not be in a bounded microwatershed or of some minimum size to satisfy fetch requirements, and no meteorological instruments or other stream gaging apparatus are required. It can be used by any labora-

*Radiological Physics Division, Argonne National Laboratory, Argonne, Ill. This article is based on a paper presented at the 3rd National Symposium on Radioecology at Oak Ridge, Tenn., May 10–12, 1971.

tory that has a conventional liquid scintillation counter and the facilities to construct a vacuum drying apparatus.

METHOD

The 200-day experiment was carried out on 12 trees in an introduced plantation of red pines (*Pinus resinosa*), which were uniform in age and size. Each tree was injected with 14.9×10^8 dpm (6.71×10^{-4} Ci) of tritiated water, which was equally apportioned among four small holes bored in the main stem of the tree, approximately 1 ft above ground level. The holes were sealed with a commercial grafting compound. Composite foliar samples were collected twice daily for the first week of each experiment and daily thereafter until tritium in the tissue water approached the limits of the counting system (20 dpm/ml). The samples were sealed in plastic bags and stored frozen. For analysis, the tissue water was extracted from the foliage by a freeze–dry technique[10] and was counted by liquid scintillation. The results, corrected for background and counting efficiency, were expressed as dpm per milliliter of tissue water and were plotted on rectangular coordinates as a function of time after the injection. The flow rate, F, through the system is found from

$$M = F \int_0^\infty f(t)dt$$

where M is the total activity injected and $f(t)$ is the specific activity of the tracer at the exit point at any time subsequent to its introduction into the system.[8] The linear transpiration rate, T (cm/day), for the stand of pines is

$$T = 24 \times 10^{-4}\ T_v P$$

where T is the linear transpiration rate (cm/day), T_v is the volumetric transpiration rate (ml/hr/tree), P is the stand density (trees/m^2) and the numerals convert hours to days, and volumetric evaporation rate to linear.

Two of the 12 trees were injected early in 1970, and, beginning April 1, two trees were injected each month for 5 months. The last foliage radioactivity measurements were made October 17.

RESULTS

Data from the two trees injected in early 1970 indicated that transpiration began only when the soil was completely thawed even though air temperatures had been above freezing for some time. Data from the other trees showed a spring transpiration rate of 0.3 cm/day. The rate rose to a maximum of 0.8 cm/day in mid-June, when available soil moisture was not rate-limiting, but dropped to 0.4 cm/day in August as soil moisture became depleted (Table 1). From April 1 to October 31, the total consumption of water by the forest was 91.4 cm, and the rainfall input was 82.5 cm, indicating only a minor overall moisture deficit for this

Table 1 Transpiration Rate in Red Pines

Tree	Date	Tree height, cm	dbh,* cm	Transpiration rate	
				ml/hr/tree	cm/day†
A	3/30–4/24			352	0.30
B	3/30–4/24			520	
1	5/5–5/26		11.4	784	0.64
2	5/5–5/26		13.3	1041	
3	6/17–6/30	870	14.1	1170	0.82‡
4	6/17–6/30	740	9.5	222	
5	7/7–7/20	750	12.1	935	0.77
6	7/7–7/20	820	13.3	1280	
7	7/21–8/6	820	12.3	725	0.40
8	7/21–8/6	650	8.2	413	
9	9/1–9/17		10.4	185	0.15
10	9/1–9/17		12.3	254	

*Diameter at breast height.
†Average of two for the same date.
‡Tree 4 not included in average.

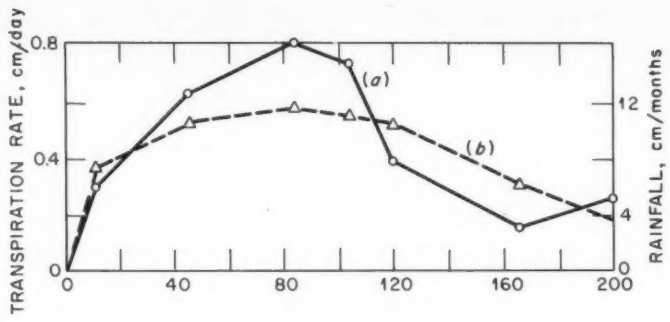

Fig. 1 Transpiration rates in red pines: (*a*) measured with ^3H_2O and (*b*) calculated by Penman's[11] method.

growing season. The deficit was, of course, greater during late July and August.

Transpiration rates were also calculated by (1) a method that requires temperature, relative humidity, wind speed, and net solar radiation as input parameters and (2) a method based on the evaporation equivalent of net solar radiation. Climatological data were obtained from the Argonne Climatological Station located about 300 m from the forest, corrected for vegetative reflectance differences between grassland and forest using the data in Ref. 12. The results of the measured values agreed with those calculated by Penman's method for the season (Fig. 1). The underestimations by Penman's method in June, when soil moisture was plentiful, were likely due to inadequate allowance for advection of heat from surrounding fields in the limited forested area, and the overestimation in late July and August was as expected since the Penman method yields potential rather than actual transpiration under conditions where soil moisture availability is limited. (MG)

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Protein Determination by Neutron Activation Analysis

By D. E. Wood*

(Summarized by Martha Gerrard)

Supplementary Keywords: *accelerator; industry, food; chemistry, analytical; activation, neutron; N.*

Abstract: *Protein in foodstuffs can be determined by neutron activation of the nitrogen and counting of the resulting gamma radiation. An instrument for automatic, nondestructive analysis of samples, which has been field tested and is commercially available, is described. This article is an updating of Report KN-69-270(R), 1969.*

Nitrogen determination by the Kjeldahl technique has been practiced in the food and feed industries and is probably the most widely accepted analytical technique in these industries today. Although this process has achieved relatively high precision over the years, it has several disadvantages, including the time required for analysis, the small sample size that can be conveniently handled, and the usual difficulties inherent in any chemical technique.

Neutron activation offers the possibility of a faster and simpler technique for measuring the nitrogen content of food products. The technique is nondestructive, and the sample can be stored for subsequent checking or further analysis. Following early experiments with a laboratory system, a prototype industrial system was constructed. A 6-month demonstration showed the system to be accurate in determination of protein in several types of feed and capable of a rate of 12 samples per hour. The system was subsequently redesigned to incorporate a new, higher power neutron generator, so that samples can now be analyzed at a rate of 30 per hour. Comparison studies made in cooperation with several feed companies have shown the analytical accuracy and precision to be as good as with the Kjeldahl process. Foods that have been analyzed include liquids, whole grain, eggs, and hay. This new version of the system, which has been field tested and is now available commercially, is described here.

*Kaman Nuclear Division, Kaman Sciences Corp., 1500 Garden of the Gods Road, Colorado Springs, Colo. 80907. The original article was presented at the 3rd National Feed Production School of the American Feed Manufacturers Association, Kansas City, Mo., May 26–27, 1969.

PRINCIPLE OF METHOD

The basic technique of the protein determination is fast-neutron activation of the protein nitrogen yielding the reaction $^{14}N(n,2n)^{13}N$, using a sealed-tube neutron generator. The ^{13}N decays (10-min half-life) by positron emission, and positron annihilation produces a 0.51-MeV gamma ray, the intensity of which indicates the amount of protein present.

Samples weighing 15 to 20 g are irradiated in polyethylene bottles, which are transported to and from the neutron generator through a pneumatic tube. A reference nitrogen sample is transported through a second tube for simultaneous irradiation. Both these samples are counted with a NaI(Tl) scintillation counter, located behind a lead shield. Irradiation and count times are 50 sec each, and the analysis is easily completed in 2 min. Interference due to phosphorus and silicon (Table 1) is minimized by a 12-min decay before counting, the decay of one sample being overlapped with the counting of another to cut the average time per sample. The small interference from potassium is corrected for, while that from hydrocarbons—due to a secondary reaction in which protons recoiling from neutron bombardment react with ^{13}C to form ^{13}N—is eliminated by subtracting a blank from the final results. This blank amounts to several hundred parts per million of nitrogen and thus

Table 1 Interfering Nuclear Reactions in Neutron Activation Analysis for Protein of Feeds

Element	Reaction	Half-life, min	Gamma radiation detected, MeV
P	$^{31}P(n,2n)^{30}P$	2.6	0.51 (positron annihilation)
	$^{31}P(n,\alpha)^{28}Al$	2.3	1.78
Si	$^{28}Si(n,p)^{28}Al$	2.3	1.78
K	$^{39}K(n,2n)^{38}K$	7.7	0.51
C	$^{13}C(p,n)^{13}N$	10.0	0.51

limits the analysis to nitrogen contents of 0.5% or greater.

A magazine loader, mounted on the storage station, receives up to 30 samples at a time. After being irradiated, the samples are returned to the storage station and dropped at the proper time into the detector for counting. From the detector they are dumped into a box for eventual storage or discard. Counts from the reference and unknown samples and the interfering activities are read out on three separate scalers. The sequencing of irradiation and counting are time-programmed. Although many manual controls are available for testing components of the system, actual operation is fully automatic, an analysis being performed by pushing the "start" button and reading the data, which are printed automatically. At some convenient time, the operator picks up the tape readout from the printer and from the data computes the percentage of protein in each sample. Feeding of the results directly (1) to an on-line computer instead of to the printer to eliminate manual calculation and (2) to a feed-formulation computer to provide direct corrections of process line variations is being developed in the field.

The assembly of the neutron generator, the irradiation station on which it is mounted, and the shielding (Fig. 1) may be placed in a well in the floor approximately 2 ft in diameter by 10 ft deep. The irradiation station contains a platform to rotate the sample and reference simultaneously, on two axes, in a plane perpendicular to the neutron beam. This double rotator equalizes the irradiation of sample and reference, even though the radiation field from a small neutron-producing target is very nonuniform.

Disadvantages of applying neutron activation for process control have included the large size of the accelerators and the heavy shielding required, together with the tritium hazards involved in changing targets. In the system described here, the irradiator is a small sealed-tube neutron generator in which the tritium is in a sealed glass envelope. When the accelerator is in operation, the tube is further sealed in a metal can 10 in. in diameter by 22 in. long. No vacuum pump is required, and the accelerator, with a 12-in.-long, 4-in.-diameter tube, is small enough that an assembly can be placed underground at minimum cost. After about 7000 analyses, the entire accelerator head, containing the neutron generator tube, can be shipped back to the manufacturer for replacement. A spare head can be installed during a scheduled maintenance period in half an hour, so that there is very little interruption in operation.

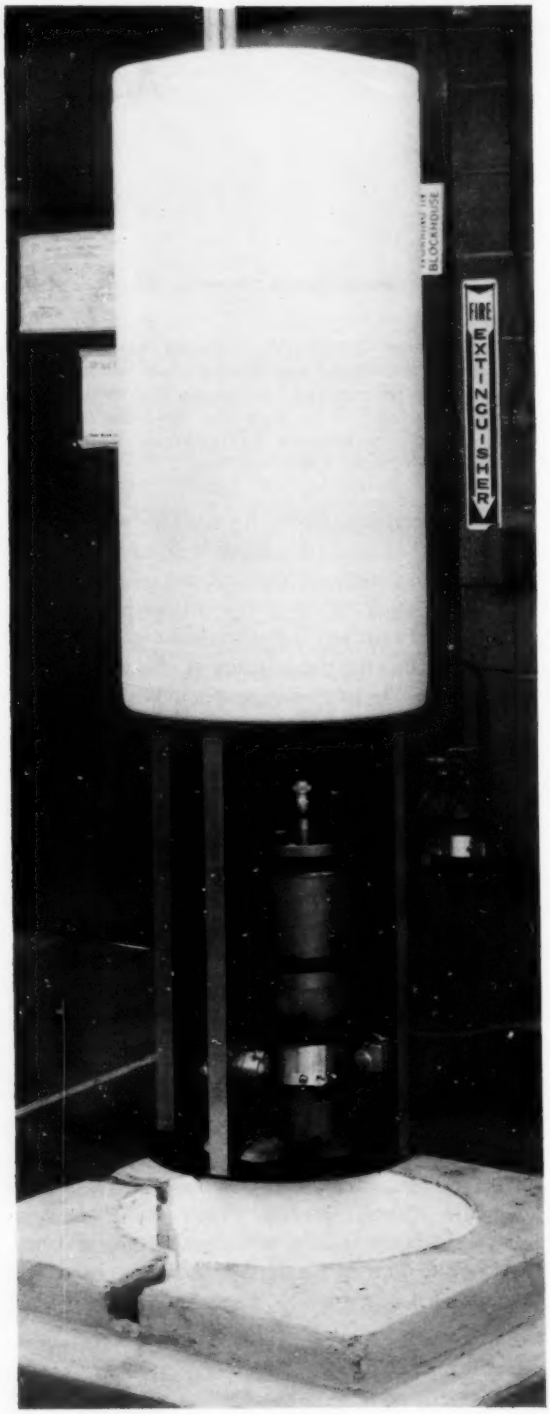

Fig. 1 Instrument for determining protein by neutron activation analysis. Shield lifted to show generator.

From the data printed out as counts on the scalers, the percentage nitrogen is calculated:

$$\% \text{ N} = \frac{C_2 - KC_3}{WC_1} \times \text{calibration factor} - \text{blank}$$

where C_1, C_2, and C_3 are, respectively, the reference, sample, and interference counts and W is the sample weight. The factor K expresses the fraction of interfering radiation that appears in the nitrogen window, and the blank measures the hydrocarbon interferences present in all samples. The instrument is calibrated with samples of known protein content (Kjeldahl analysis) (Fig. 2). Laboratory background is subtracted from all counts by prewiring the scalers so that they reset to the negative value of the background rather than to 0.

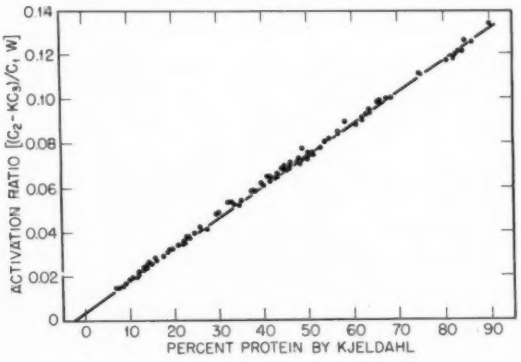

Fig. 2 Calibration of protein determiner.

The reproducibility of the activation-analysis technique was shown in a study with 20 types of food products, using several samples of each product and making several runs on each sample. The average coefficient of variation was 1.3%. The protein contents of the samples varied from high to low, and there were several levels of interference, several grain sizes, and small density variations. The samples were not ground, as would be necessary for Kjeldahl analysis and which introduces segregation effects in the samples.

ECONOMICS

The unit has been field tested by the Ralston Purina Co. in St. Louis. Analysis costs are estimated as about 60 cents per sample, including amortization of capital equipment, operator's salary, expendable materials, and maintenance. Kjeldahl analyses are estimated to cost from 90 cents to $1.50 per sample. The neutron activation installation would be expected to pay off within 2 years for a plant handling 25 to 50 thousand tons of feed annually. The instrument developers believe that rapid response to protein variation in the product constituents could produce a protein saving of approximately 1% in the finished products. Since protein costs approximately $1 for 1% per ton, the savings to an operation processing hundreds of thousands of tons of feed per year could be quite substantial.

The field test indicated that the nuclear instrument creates substantially less hazard than the Kjeldahl method, which under current conditions is responsible for more than half the laboratory accidents and injuries that occur.

IONIC ^{135m}Ba: A NEW AGENT FOR BONE SCANNING*

Supplementary Keywords: *medicine; diagnosis.*

Bone lesions were localized on scans made 1 or 2 days after injection of 1.2-day $^{135m}BaCl_2$. The 1 to 2 mCi of ^{135m}Ba used, administered as the chloride, gave better scans than ^{131}Ba or ^{85}Sr with less than half the patient radiation exposure. The ^{135m}Ba was made by irradiation of 70 to 85% enriched ^{134}BaO with a reactor neutron flux of 2×10^{15} n/(cm^2)(sec) for 3 days.

*Abstract of article by F. Hosain, I. B. Syed, H. N. Wagner, Jr., and J. K. Poggenburg, *Radiology*, **98**: 684-686 (1971).

USE OF RADIOACTIVE ^{125}I FOR DENTAL IDENTIFICATION IN MASS DISASTERS*

A method for identifying victims of mass disasters by means of dental X rays made with ^{125}I is described. By proper positioning of the ^{125}I source in the oral cavity, the entire dentition can be recorded at one time. The procedure is much more satisfactory and much less cumbersome than the use of an X-ray machine.

*Abstract of article by D. Graham, *Journal of Forensic Sciences*, **15**: 553-564 (1970).

X-RAY THERAPY OF NONTUMOROUS DISEASES*

The effectiveness of low-dose X-ray therapy for nontumorous diseases is discussed. The 312 patients treated suffered from such conditions as arthritis, bursitis, inflammation, osteomyelitis, phlebitis, and spondylitis. Single doses were from 5 to 15 R, and total doses did not exceed 150 R for cases of inflammation or 250 R for degenerative conditions. Two-year follow-ups showed recovery in 93% of the patients.

*Abstract of article by I. A. Pereslegin and V. I. Khodyrev, *Meditsinskaya Radiologiya*, **6**(1): 6-9 (January 1971) (in Russian).

Section

VI

Isotopes and Radiation Technology

Safety

Symposium: Radiation Legislation–Its Meaning to the Radiologist*

By K. Z. Morgan, J. N. Neel, and H. L. Friedell

(Summarized by Helen P. Raaen)

Supplementary Keywords: *medicine; diagnosis; therapy; radiology; radiation source; source, X-ray; accelerator; safety; regulation; U;* ^{226}Ra; ^{228}Ra; ^{210}Po.

In a symposium*† on *Radiation Legislation—Its Meaning to the Radiologist*, three men, each preeminent in his particular field, presented their views on Public Health Law 90-602, "Radiation Control for Health and Safety Act of 1968." The legislation has implications for radiology and manufacturers of radiological equipment. K. Z. Morgan, Ph. D.,‡ spoke for the radiation physicists, J. N. Neel§ for the legal profession, and H. L. Friedell, M.D.,¶ for the radiologists. Pertinent points were brought up in the discussion after their presentations. Summaries of the papers** follow.

WHY THE 1968 ACT FOR RADIATION CONTROL FOR HEALTH AND SAFETY IS REQUIRED (K. Z. Morgan)

Morgan spoke chiefly about medical X rays but did not exclude other types of radiation. For the purpose of the symposium, he emphasized that the law includes all types of man-made ionizing radiation—both electromagnetic and particulate. The particulate radiations include not only the alpha, beta, positron, neutron, and fission-recoil radiations from man-made or artificially produced sources, but also the alpha and beta radiations from concentrated and/or fabricated natural-radiation sources prepared by man, e.g., sources of ^{226}Ra, ^{228}Ra, ^{210}Po, and natural uranium.

He suggested the possibility that consideration will be given under PL 90-602 to reducing natural-background radiation dose to the population by recommending that certain building materials which are high in uranium and thorium ores be avoided as construction materials for homes, schools, and factories. Such precautions could be significant; for example, in Tennessee, cement blocks are often made from Conasauga shale, and in Florida these blocks are sometimes made from phosphate rock. Both of these minerals contain a fairly high concentration of uranium ores, and, in homes having a recirculating air supply, the radon gas from the uranium seeps out of these blocks and reaches equilibrium with its daughter products that are continuously recycled in the atmosphere. In such homes, the lung dose is frequently 10

*Presented by the Radiologists–Manufacturers Committee at the Fifty-Fifth Scientific Assembly and Annual Meeting of the Radiological Society of North America, Chicago, Ill., Nov. 30–Dec. 5, 1969.

†Moderated by: (*a*) J. S. Krohmer, Ph. D., Chairman, Radiologists–Manufacturers Committee, Radiological Society of North America, and (*b*) V. P. Collins, M.D., Representative, Subcommittee on Devices, American College of Radiology.

‡Director, Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tenn.

§Attorney, Frankfort, Ky.

¶Professor of Radiology, Case–Western Reserve University, Cleveland, Ohio.

**The full papers are published in *Radiology*, 99: 570-579 (1971).

times the average dose. In addition, PL 90-602 covers a host of accelerator- and reactor-produced radionuclides that are not under the direct responsibility of the AEC and covers all types of radiation sources that may be imported into the United States. Most importantly, it covers all sources of common X rays, a few of which he listed for illustration (Table 1).

Table 1 Typical Common X-Ray Sources

Medical diagnostic X ray	High-voltage vacuum switch
Medical X-ray-fluoroscopy equipment	High-voltage vacuum condenser
Medical therapeutic X ray	High-voltage rectifier
Dental X ray	High-voltage regulator
Mass chest X ray (portable photofluorometric)	Television
Industrial X ray	Shoe-fitting machine
Electron microscope	Van de Graaff, Cockcroft–Walton linear accelerators, cyclotrons, betatrons, and many other high-voltage accelerators
X-ray diffraction equipment	
X-ray spectrometer	
X-ray inspectoscope	

Morgan summarized (Table 2) the principal man-made sources of population exposure to ionizing radiation in the United States, showing the major role played by medical exposure. The dose from weapons fallout is relatively small and declining steadily. The dose of ~0.6 mR/year from occupational exposure is very low but can be expected to increase considerably as the nuclear energy industry and the use of radioisotopes increase. Radiation from miscellaneous sources undoubtedly will increase because many new types of electronic products added each year to the public market will find their way into research laboratories, industries, hospitals, public schools, and homes. The doubling time for the number of annual medical X-ray examinations in the United States has been ~13 years and may be decreasing because of expansions in Medicare and Medicaid. Morgan believes that we cannot afford to permit—and that PL 90-602 will not allow—this increase in the use of ionizing radiation in research, education, medicine, industry, and domestic applications to be an excuse for increasing the average population dose.

Table 2 Estimated Average Ionizing-Radiation Exposure to Persons Living in the United States

	mrems/year
Medical exposure	
Gonad dose from diagnosis (1964)	55
Gonad dose from therapeutic use (1964)	7
Bone-marrow dose from diagnosis (1964)	125
Thyroid dose from diagnosis (mostly dental) (1964)	1000
Weapons fallout dose (1968)	2
Occupational exposure	
Nuclear energy industry gonad dose (1966)	0.2
All other occupational exposure gonad dose (1966)	0.4
Other man-made sources (watches, television, shoe-fitting machines, radioisotope applications, etc.) gonad dose (1966)	0.1

The author pointed out (Fig. 1) that the summation of all the benefits of all forms of radiation (ionizing plus nonionizing) must be balanced against the summation of all the risks to the total population, including future generations. He believes evaluation of this balance is a most important responsibility of those government agencies who must implement Law 90-602. His suggested levels of permissible exposure (Table 3)—together with the realization that no matter how small the exposure, the probability of its inducing serious damage is *not* zero—should be a useful guide in ensuring that the benefits always exceed the risks.

The author estimates that 94% of man-made exposure to ionizing radiation is from medical exposure, and 90% of this is from diagnostic rays. All use of medical X rays should be restricted to those who meet minimum requirements of education, training, and certification in the proper and safe use of this tool. There is no doubt that the medical benefits of ionizing radiation far exceed the medical risks, but medical diagnostic exposure to the population can be reduced to no more than 10% of its present level.

THE RADIATION CONTROL FOR HEALTH AND SAFETY ACT OF 1968—ITS IMPACT ON THE RADIOLOGIST AND THE STATES (J. N. Neel)

Neel believes that the real intent of the Radiation Control for Health and Safety Act of 1968 was to confer on the federal government jurisdiction over sources of ionizing radiation that it could not control without Congressional authorization. Prior to the Act, the states were responsible for radiation protection: laws were adopted in 47, registration of radiation

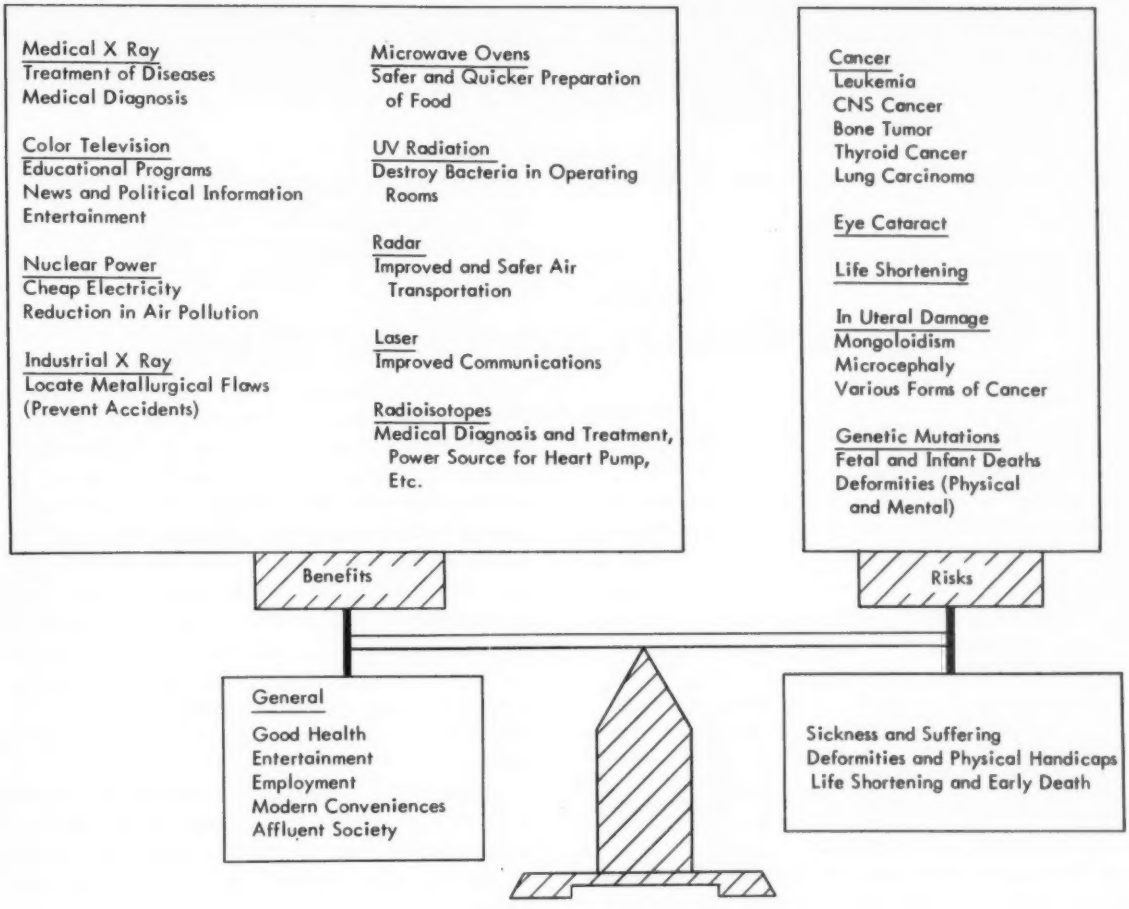

Fig. 1 Benefits vs. risks of radiation.

sources was authorized in 49, 20 had entered into agreements with the AEC for regulatory control, and 41 had regulations for the control of sources of ionizing radiation. He believes that control over sources of ionizing radiation, excluding AEC materials, should be kept in local hands. His comments are based on a review of Congressional hearings that preceded the passage of Law 90-602.

Two recommendations are made to the Radiological Society of North America as means to oppose further entrenchment of federal bureaucracy over the control of the possession and uses of sources of ionizing radiation:

1. Immediate organization of committees at the national, regional, state, and local levels to oppose any prospective legislation that would give the federal government power to establish and carry out a regulatory program to control health hazards associated with the possession and use of medical X radiation.

2. Authorizing the state committees to immediately commence an evaluation of the status of the competency and efficiency of radiological health programs in each state for the purpose of making recommendations to the governor, the state legislature, and the state health department of steps the respective states should take to upgrade and improve their programs for the control of the possession and use of sources of ionizing radiation.

The author seems adamant in his belief that the health and safety of our citizens, as well as the

Table 3 Suggested Levels of Permissible Genetic and/or Total-Body Exposure of the U. S. Population to All Man-Made Sources* of Ionizing Radiation That Might Be Adopted by the Federal Radiation Council for Application in the United States

500 mrems/year to any critical segment of the population

5000 mrems/30 years as the maximum

170 mrems/year as an average as follows:

	mrems/year
Internal dose from nuclear power operations	50 (5)†
Internal dose from other industrial operations	30 (3)
External dose from nuclear power operations	17 (2)
External dose from other industrial operations	15 (2)
Medical (diagnostic)	40 (5)
Medical (therapeutic)	10 (5)
Occupational‡ contribution to population dose	4 (0.1)
Weapons fallout	2
Miscellaneous (watches, television, high-voltage switches, etc.)	2 (0.1)
Total	~170 (22)

*This includes medical exposure but excludes natural background. It includes also exposure from natural radioactive sources such as uranium, thorium, ^{226}Ra, ^{228}Ra, ^{210}Pb, etc., that have been concentrated by man and includes exposure in uranium or thorium mining operations.

†The values in parentheses are those Morgan believes we can attain. Since this is a long-range extrapolation, some of these values are larger and others are smaller than the present estimates of population doses from the source.

‡Exclusive of the nuclear power operations and related industries.

preservation of our individual liberty and freedom, demand that we not allow creeping federalism to gain control over one of the most important and beneficial tools of medical diagnosis, therapy, and research.

THE RADIATION CONTROL FOR HEALTH AND SAFETY ACT OF 1968—A RADIOLOGIST'S POINT OF VIEW (H. L. Friedell)

In the briefest and most philosophical of the three papers, Friedell reiterates that in discussing permissible dosage it is important to consider information per unit of dose. While reduction of dose is an unassailable goal when radiation is improperly used, its reduction after obvious errors are corrected results in inadequate information. It is the physician who must weigh benefits against hazards; to introduce some kind of regulatory mechanism into decision-making is dangerous. The benefits of ionizing radiation have been conservatively estimated. There should be an effort to educate, to provide more information, and to upgrade training and experience, but not to determine exactly how value judgment is to be made. This was the essence of a radiologist's point of view about Law 90-602.

In the lively discussion that followed the papers, V. P. Collins pointed out the dilemma of all those concerned with Law 90-602—the obligation to make the right decisions on inadequate information. From the discussion in general, there was an overall appeal for understanding and cooperation among all persons and agencies connected with the implementation of the new legislation.

Section
VII
Isotopes and Radiation Technology

Isotopes Around the World

Finnish Applications of Radioisotopes

By J. Kuusi*

The aim of the Applied Radiation and Isotopes Division of the Reactor Laboratory in Otaniemi is to promote the applications of radioisotopes in Finland, to develop new methods and applications in the field of isotope and radiation technology, and to produce radioisotopes for industrial and medical use. The number of persons on the technical staff varies with the number of undergraduate and graduate students doing diploma and thesis work but is usually about 15. There are three sections: Radioisotopes Application, Radioisotope Production, and Activation Analysis.

The main projects of the Radioisotopes Application Section are (1) the development of radioisotopic methods of analysis for industrial quality and process control and waste-water problems, (2) research and service work connected with tracer studies of industrial processes, and (3) special studies on the use of radiation and radioisotopes. Development work on radioisotopic methods of analysis is mainly connected with applications of radioisotopic X-ray techniques and radioisotopic-source neutron activation analysis. Radioisotopic X-ray gages and analyzers have been developed for on-line and laboratory use for the papermaking and metallurgical industries, and an activation analyzer, developed in cooperation with industry and having a radioisotopic neutron source, has been installed for off-line process control of a chrome-concentration process [*Isotopes and Radiation Technology*, 9(1): 48–53 (Fall 1971)]. Use of high-resolution solid-state X-ray detectors in radioisotopic X-ray techniques, determination of some light elements by this technique, and evaluation of the potential applications of the new, high-intensity isotopic neutron sources are perhaps the areas of the greatest interest at present. Tracer studies of industrial processes include mixing, flow, leakage, and general process studies and development of measuring instruments and methods for data handling. Special studies involve small, individual projects using radiation, radiochemical methods of analysis, or radioisotopic techniques—frequently done by undergraduate students. They include, for example, a study of the diffusion of cooking chemicals in wood chips by neutron activation analysis of microtome cuts of chips from various stages of impregnation processes.

Development of labeling methods and starting the production of ^{131}I are the main projects of the Radioisotope Production Section. The aim of the semicommercial labeling project is to produce certain labeled compounds—e.g., ^{131}I-labeled Hippuran, ^{57}Co-labeled vitamin B_{12}, and various ^{99m}Tc-labeled compounds—in cooperation with medical industry, hospitals, and research laboratories. The ^{99m}Tc project is planned to be a part of a growing Scandinavian cooperation in the field of radioisotope production. Production of ^{131}I has been the main effort of the Section, with establishment of an adequate production laboratory and facilities and completion of the necessary preliminary studies. The project is being carried out in close cooperation with a medical firm, which distributes the ^{131}I produced. The Radioisotope Production Section is also responsible for irradiation services.

The Activation Analysis Section has been chiefly involved in applications of neutron activation analysis in environmental studies, geology, medicine, and industry. In addition, some specific methods for chemical separations after irradiation have been developed.

*Director, Applied Radiation and Isotopes Division, Reactor Laboratory, Otaniemi, Finland.

Considerable effort has been expended on the determination of mercury in fishes in connection with the study of mercury pollution. This project is continuing in cooperation with other research laboratories and authorities. Another environmental study was the determination of distribution of ^{133}Cs in fishes, plants, and human muscles. Geological studies have included analysis of turf and stone for molybdenum and tungsten, and meteorite and moon-rock samples have been analyzed. Trace elements have been determined in various biological samples, and elements have been determined in both micro and macro concentrations in industrial samples. Characteristic of the problems handled is that solving them with other methods of analysis is difficult or impossible. The Section also consults with representatives from industry, medicine, and other research laboratories on trace-element determinations, participates in research projects in this field, and performs routine service analyses. In 1969, approximately 700 activation analyses were made for customers, 400 of these being mercury determinations.

The Applied Radiation and Isotopes Division has expanded greatly during the last few years, and projects have been going only a relatively short time. However, the results thus far obtained and the interest in the projects shown by industry, hospitals, and research laboratories indicate that the group is useful. (MG)

Section

VIII

Isotopes and Radiation Technology

Miscellaneous

Availability of Isotopes and Services

ORNL ISOTOPES INFORMATION CENTER TO SHUT DOWN

Owing to lack of financial support, ORNL's Isotopes Information Center, supported for the past 9 years by the AEC's Division of Isotopes Development, will cease operation effective June 30, 1972. The Center, in addition to publishing *Isotopes and Radiation Technology* (see inside front cover), has prepared a number of translations, compiled numerous bibliographies and state-of-the-art reviews, and has published the "Isotope User's Guide" and revisions of "Special Sources of Information on Isotopes." In addition, it has served as a focal point for thousands of inquiries dealing with the production and applications of isotopes and radiation.

AERE ISOTOPE BUREAU

The British Atomic Energy Research Establishment (AERE) is offering, through its Isotope Bureau, service to industry in the application of radioisotopes and radiation techniques to practical problems. Fields of interest include radioisotopic instruments, tracer techniques, and radiation processing. Reasonable charges are levied for services rendered. Details of the Bureau's capabilities may be obtained from Manager, The Isotope Bureau, AERE, Harwell, Didcot, Berks., England.

RADIATION ENGINEERING—A NEW FIELD FOR UNDERGRADUATES

The Department of Nuclear Science of the Technion-Israel Institute of Technology, in Haifa, is now offering two new courses in radiation engineering, one lasting one semester and one lasting three semesters. In the shorter program, the attention of students will be drawn to the possibility of solving problems by radiation techniques. In the longer (three semester) program, the student will acquire the ability to optimize and design radiation systems.

A direct result of the new program is the increased interest already shown by the academic staff of the engineering faculties in the applications of nuclear radiation in their specific fields. The slow penetration of nuclear methods in industry seems to be due to the lack of attention to radiation engineering. It is hoped that a suitable curriculum and textbooks will increase activity in this promising branch of technology.

PORTABLE DENSITY–MOISTURE GAGE

A portable (32 lb) radioisotopic gage, containing 50 mCi of ^{241}Am–Be and 10 mCi of ^{137}Cs, is announced by Campbell Pacific Nuclear Corp. (130 Buchanan Circle, Pacheco, Calif. 94553) for in situ measurement of moisture and density of fuels, embankments, asphaltic concrete, etc. The manufacturer will assist users in obtaining a license for use and will train operators.

PYROGEN-FREE ^{18}F

The availability of sterile, pyrogen-free ^{18}F (as NaF), in a form suitable for injection, is announced by PPB, Inc. (Research Reactor Facility, Research Park, Columbia, Mo. 65201). Deliveries within 500 miles of the laboratory are made by private aircraft.

INTERNATIONAL NUTRONICS PROVIDES SERVICES

International Nutronics Inc., 200 Third Street, Los Altos, Calif. 94022, has been operating a 30-thousand-Ci commercial ^{60}Co irradiation service facility since

June 1970. They plan to expand this facility to 1 million Ci within 5 years. Materials irradiated include medical and surgical equipment, pharmaceutical products, cosmetics, minerals, and wood–plastic and concrete–plastic composites. Radiosterilization of surgical equipment and pharmaceutical products accounts for 85% of the items. In addition, International Nutronics also offers radiation-protection services—consulting, training of personnel, evaluation of facilities and procedures, radiation surveying, decontamination, leak testing of sources, etc.

MICRO-GAMMATROL, INC., FORMED

A new company, Micro-Gammatrol, Inc., is a joint venture owned equally by Neutron Products, Inc., of Dickerson, Md., and Micro-Biotrol Company, a Division of The Griffith Laboratories, Inc., of Chicago. The company will offer and perform radiation sterilization services and will market radiation processing facilities designed and constructed by Neutron Products. Initially, the radiation sterilization services will be performed by Neutron Products, but Micro-Gammatrol will eventually have its own radiation processing facilities.

ISOTOPIC GAGES

Three radioisotope-based instruments—a thickness gage, a coating weight gage, and a gamma relay—are announced by Weston Components Division (Archbald, Pa. 18403), who market the instruments for the French manufacturer, Nucleometre. The gages may be mounted in either a C or an O frame and can be used in a backscattering arrangement if only one side of the strip being measured is accessible. Several heads—containing, e.g., ^{147}Pm, ^{85}Kr, ^{90}Sr, or ^{241}Am—are available, the selection being made according to the thickness range to be measured. The gamma relay contains ^{60}Co or ^{137}Cs and controls process steps by activating an alarm or a valve when the level of material in a tank, for example, drops too low. The instruments are suggested for the metallurgical, textile, food, glass, and cement industries, to mention only a few.

NEW GAGES MARKETED FOR THE FOOD INDUSTRY

A line of gages that, at present, are being used primarily in the food industry is being marketed by Nuclearay, Inc., P. O. Box 9320, NW Station, Austin, Tex. The company manufactures process-control systems based on backscatter and transmission of radiation. The backscatter gages can be used to measure density or thickness of sheet material. The transmission gages can be used to monitor density of material flowing through a pipeline or to monitor the level of liquid fill. One liquid-level gage marketed by Nuclearay is designed to monitor fill of milk cartons; a variation as small as $\frac{1}{32}$ oz can be measured. In addition to applications in the dairy industry, the company has applied its gages to salad dressing and tamale lines, and an ice-cream-density control system and a level monitor for high-speed canning and bottling lines are being developed.

^{85}Kr LEAK DETECTOR

The new TRW Systems Group (One Space Park, Redondo Beach, Calif. 90278) radiotracer leak detector, model SC-69, uses trace amounts of ^{85}Kr to measure leaks in about 2 hr—at ambient pressure and with minimum equipment. Leak rates as small as 2.8×10^{-6} cm^3/sec have been measured, and sensitivity for measurement of a propulsion-system leak has been shown to equal that of a vacuum–mass-spectrometer technique. The system is also potentially useful for life-support, fuel-handling, and pneumatic-pressurization systems; aircraft fuselage sections; submarine hulls; railroad tank cars; toxic gas–liquid systems in the oil industry; and gas-supply systems.

AEC Activities

NUCLEAR TECHNIQUES FEATURED IN NEW OVERSEAS EXHIBIT

The U. S. exhibit, "Nuclear USA," at the Fourth United Nations International Conference on the Peaceful Uses of Atomic Energy, Sept. 6–16, 1971, in Geneva, Switzerland, depicted nuclear techniques developed in response to such world needs as pollution control, electric-power production, release of trapped geological resources, and heart-assist devices. The

display, covering a dozen different topics, designed by the U. S. Atomic Energy Commission, incorporated some $1.5 million worth of equipment on loan from U. S. industry and occupied ~20,000 ft^2. Implantable radioisotope-powered heart-pacer and heart-pump devices were displayed along with a simple artificial-kidney cartridge. Also displayed were lunar rock samples, a SNAP-27 generator of the type providing power for the instruments on the moon, and a SNAP-19, the type providing supplementary power for the Nimbus-III weather spacecraft experiment launched in 1969 and still sending data. The National Aeronautics and Space Administration demonstrated how nuclear techniques can be used for ultrarapid analysis of various kinds of samples, such as environmental materials and drugs, via satellite and computer.

SOUTHERN INTERSTATE NUCLEAR BOARD GETS CONTRACT FOR TRAINING STUDY

The Southern Interstate Nuclear Board (SINB) of Atlanta, Ga., has been awarded a $5000 contract by the Atomic Energy Commission to study current educational standards and techniques as related to training of technicians for the nuclear industry. Personnel in a dozen companies will be interviewed concerning the training required for their jobs. Findings from the study will be presented at a 2-day Nuclear Technician Manpower symposium, tentatively scheduled for early 1972, for educators and for representatives of government and industry who employ trained nuclear technicians.

BULLET HOLES IDENTIFIED WITH ISOTOPIC ANALYZER

A portable isotopic X-ray-fluorescence analyzer is being field-tested by the Dade County Public Safety Department in Miami, Fla., to determine its usefulness in identifying bullet holes. The instrument detects lead residues around holes made by bullets—an element that is probably absent when a hole has been made by another method.

NEW PHOTOSYNTHESIS FILM

A new color motion picture, *Controlled Photosynthesis,* which shows how ^{14}C is used in determining the chemical precursors of food sugars in the photosynthesis process, has been produced by the Lawrence Radiation Laboratory, Berkeley, Calif. Included in the film are discussions of current enzyme research which shows promise for increasing the production of protein in plant leaves. The film may be obtained free on loan, except for return postage, from the Motion Picture Film Library, U. S. Atomic Energy Commission, Oak Ridge Operations, Oak Ridge, Tenn. 37830.

THE RADIOISOTOPE INDUSTRY—1971

Speaking at the Atomic Industrial Forum's Annual Conference in Washington, D. C., November 1971, Dr. Glenn T. Seaborg presented statistics on radioisotope sales and listed manufacturers of radionuclides and related products. The market for cyclotron-produced radioisotopes is $3 x 10^6 to $4 x 10^6, with seven commercial companies actively engaged in their production. Withdrawal of the AEC from isotope production is reflected in a decrease in AEC sales of reactor-produced isotopes from $2.3 x 10^6 in 1966 to $1.2 x 10^6 in FY 1971. However, the overall market for radioisotopes is expected to grow 10 to 12% each year for the next several years. About 40 organizations have been approved to receive ^{252}Cf loans for participation in a program of evaluation of applications of this nuclide.

Fission-product radioisotopes—chiefly ^{90}Sr, ^{137}Cs, and ^{147}Pm, with some interest in ^{85}Kr, Xe, Pd, and Rh—are used in industry, medicine, and research. AEC sales of the first three of these amounted to $337 thousand in FY 1971.

Thirty-five industrial firms are listed as processors, i.e., firms that prepare irradiation targets, separate the isotopes, and prepare radiochemicals, labeled compounds, or radiopharmaceuticals for distribution. Thirty-one firms produce alpha, gamma, and neutron sources, with an estimated $4 x 10^6 to $5 x 10^6 annual sales.

Radiation sources are used in radiographic and teletherapy units, gages, irradiation facilities, isotopic power generators, and self-illuminating devices.

Four principal suppliers of radiographic equipment are listed, which have an annual sales volume of $2.5 million. Six thousand radiographers are employed by firms licensed to make radioisotopic radiographs, with 10 to 15 thousand persons employed in the overall programs. Seven firms are listed as supplying teletherapy units.

Thirty firms are active in the radioisotopic gage field. Estimated sales for FY 1971 are $53 x 10^6; the 1965 value was $30 x 10^6. Beta-emitting radioisotopes

are used in self-illuminating signs and devices, which are manufactured by six firms. In 1971, AEC sales of ^{3}H, the nuclide used most frequently, were $\$148 \times 10^3$ and of ^{85}Kr, $\$89 \times 10^3$.

Substantial commercial markets could develop for radioisotopic power sources, e.g., in direct-broadcast satellites, for marine and remote-land power, and in cardiac pacemakers and artificial hearts. Twelve firms are listed as active in this field.

Twenty-three firms are listed as active in radiation processing, 60% using ^{60}Co and the rest accelerators. The activities include induction of polymerization, manufacture of heat-shrinkable film and tubing and of wood–plastic composites, curing of coatings, making of soil-release and permanent-press fabrics, sterilization of medical products, synthesis of ethyl bromide and of the flocculant "Atlasep," and offering of irradiation services. Accelerators are made by a dozen firms, and radioisotopic sources are manufactured by half a dozen. (MG)

LARGE SHIPMENT OF ^{137}Cs TO FRANCE

The Atomic Energy Commission's Oak Ridge National Laboratory shipped, in March and June 1971, a total of 200 thousand Ci of ^{137}Cs to France, one of the largest shipments ever made of this material from ORNL, and valued at $25 thousand. The ^{137}Cs is recovered from reactor-fuel-processing waste, which is shipped to ORNL from the AEC's Hanford Operations in Richland, Wash.

General

AECL EXAMINING ITS RADIOISOTOPES RESEARCH AND DEVELOPMENT PROGRAM

Following a critical study of its radioisotopes research and development program, Atomic Energy of Canada Limited's Commercial Products group is giving top priority to projects related to health care—an area that ranks high in social desirability and where limited resources can be effectively applied. Food irradiation and industrial troubleshooting will be cut back. The slow pace at which the food industry is turning to irradiation techniques for extending product shelf life, after more than a decade spent by AECL on extensive research in food irradiation, has been disappointing. Nevertheless, Canada still wishes to participate in an international project on wholesomeness. An application to the Food and Drug Branch, Department of National Health and Welfare, on the irradiation of poultry and fish will be pressed, and hardware development for food irradiation will continue. In the industry troubleshooting area, the consultation that has been made available to industry on a service-fee basis has elicited some interest, but the response has not been nearly great enough to make the effort commercially viable.

AECL's marketing strength in the medical area, developed by its pioneering efforts in ^{60}Co teletherapy and, in recent years, through the sale of industrial irradiators for sterilization of hospital supplies, should be reinforced by the redeployment. The expertise residing in the industrial applications group, headed by R. W. Tolmie [see *Isotopes and Radiation Technology*, 9(2): 209-214 (Winter 1971–1972)], is relevant to any innovative approach to diagnostic techniques. And the knowledge gained in using gamma radiation for medical disposables will be applied to the sterilization of other products.

NAVY'S FIRST RTG PASSES FIFTH ANNIVERSARY

The Navy's first commercially procured radioisotopic thermoelectric power generator completed 5 years of operation on Aug. 11, 1971. The generator, marketed by Martin Marietta Corporation as LCG-25A and designated RTG-1 by the Navy, provides power for a weather data collection and telemetering station on Fairway Rock in the Bering Strait about 15 miles from the Alaskan coast. (Details of the generator are given in Table 3 of the article by R. T. Carpenter in Sec. IV of this issue.) This generator was the first commercial radioisotopic generator sold in the United States.

Fairway Rock is inaccessible for all but a few weeks during the summer. When the Navy reached its decision to use a radioisotopic power generator for this station, only a limited time was available for manufacture and licensing. The AEC and Martin Marietta Corporation cooperated closely with the Navy in

handling safety reviews and license applications. Because of the limited time, the generator had to be provided with an already obsolescent thermoelectric power converter. Inclement weather on annual visits to the site has prevented exchange of the converter for an improved assembly. Nevertheless, the generator has performed perfectly since its installation. In the summer of 1966, the generator had an output of 26.4 W(e); in June 1971, the generator was still providing 18.8 W(e), more than sufficient to enable the unit to surpass its 5-year design life.

INTERNATIONAL INDUSTRIAL IRRADIATION ASSOCIATION

The recently organized Association Internationale d'Irradiation Industrielle (headquarters: 22 Boulevard G. Clemenceau, 92 Courbevoie, France) is a professional organization whose Board will have a representative from each country. The objective of the Association is to establish cooperation between fabricators and users of industrial irradiation facilities, and membership will be open to persons interested in either accelerator or radioisotopic sources of ionizing radiation.

In the planning stage is an international document on irradiation techniques, indicating the power levels (in kilowatts), accelerators in industrial use with their energy levels, and capacities (^{60}Co and ^{137}Cs).

Information on the new association may be obtained from

M. P. Vidal, President
Conservatome S. A.
22 Boulevard G. Clemenceau
92 Courbevoie, France

MEDTRONIC TO BUILD $2.5 MILLION RESEARCH CENTER

Medtronic, Inc., of Minneapolis, manufacturer of biomedical engineering devices (most notably the cardiac pacemaker), expects to complete a $2.5 million animal research facility on a 57-acre site in Coon Rapids, Minn., in 1972. The facility will have animal holding areas for a large variety of species, a surgical and radiological suite, ultraclean vertical laminar air flow, and laboratories for toxicity studies, clinical chemistry, and hematology.

For FY 1971, Medtronic reports a net sales of $30,565,532, which is 21% greater than the year before.

SEMINAR ON RADIATION QUANTITIES

A seminar on radiation quantities is scheduled for May 9–12, 1972, at the National Bureau of Standards, Gaithersburg, Md. Measurements of four types will be covered—X rays, electrons, neutrons, and radioactivity. For each category, the principles of measurement and the important instruments will be discussed. Preparation of standard radioactive materials will be included.

For information, contact E. H. Eisenhower, Center for Radiation Research, National Bureau of Standards, Washington, D. C. 20234.

RADIOISOTOPE-POWERED BATTERY FOR ELECTRIC WRISTWATCHES

Aktiebolaget Atomenergi (Studsvik, Sweden) is working on a new type of radioisotope-powered battery, which depends on direct charging through a dielectric. The energy comes from tritium–lithium or titanium tritide—whose 18-keV beta particles pass through a 0.5- to 2-μ insulating layer and then impinge on a thin aluminum foil, charging it negatively. The maximum power density is 2 μW/cm^2, from which 3.5 nW/cm^2 of electricity can be obtained, i.e., a 0.17% conversion efficiency. The surface area needed to produce 10 μW could probably be obtained with a rolled band, like a paper condenser.

FIRST PATENT-SHARING AGREEMENT WITH USSR MADE BY ENERGY SCIENCES

An exclusive license agreement has been signed between Energy Sciences, Inc. (Burlington, Mass. 01803) and the Institute of Nuclear Physics (Novosibersk, Siberia) of the USSR Academy of Sciences to permit U. S. production of Russian-designed accelerators. These accelerators are said to be simple, lightweight, less than half the size of comparable U. S. equipment, and highly reliable and to have low maintenance requirements. The agreement is for 10 years, with renewable options.

Plans are to have the equipment on the U. S. market in 1972.

BRIEFS ON TRITIUM

Brief summaries of three of the papers presented at the *Tritium Symposium*, held at Las Vegas, Nev., Aug. 30–Sept. 2, 1971, are included here.

^3H-Labeling of Biochemicals. R. Ehrenkaufer and A. P. Wolf, Brookhaven National Laboratory, and W. Hembree and colleagues, Columbia University, report that biochemicals can be labeled with ^3H without losing biological activity. Their new labeling method uses a microwave discharge to break $^3H_2$ into atoms, which then pass over the compound to be labeled. Adrenocorticotrophic hormone, with activities at least 1000 times those achieved previously, retains all its biological activity.

Malignant-Tumor Therapy. High-specific-activity tetracycline–^3H causes partial to total remission of spontaneous mammary tumors in rats, say Paula Wood, J. Haury, and L. Wood, Lawrence Livermore Laboratory. Malignant tumors preferentially absorb the tetracycline–^3H.

Gene Damage from ^3H-Labeled Luminous Compounds. Damage to their kidney- and lung-cell chromosomes occurred when Chinese hamsters received, for 8 hr, 5-mg (100- or 1000-μCi) doses of tritiated luminous compounds coated on their skins. The observation was made by Mayme C. Colvin and J. M. Everts, EPA's Eastern Environmental Radiation Laboratory, Montgomery, Ala., who conclude that the compounds are a possible hazard to those who work with them.

BASIC METAL INDUSTRIES SYMPOSIUM SET FOR HELSINKI DURING SUMMER OF 1972

In recognition of the increasingly important role of isotopes and radiation in this field, the International Atomic Energy Agency has scheduled a Symposium on the Use of Nuclear Techniques in the Basic Metal Industries, to be held in Helsinki, Finland, July 31–Aug. 4, 1972. The meeting is intended to cover all stages in the manufacture of basic metal products and closely related operations, from mineral processing through melting, refining, and alloying operations to the rolling-mill or extrusion, lamination, and coating processes.

A provisional list of topics to be considered at the symposium is given below, for guidance only. These topics may not all be treated in detail, depending on contributions received and on the decisions of the Selection Committee on papers in certain subject areas.

(*a*) Mineral processing:
Review of mineral processing methods and applications and potential uses of radioisotopes; progress in laboratory analysis and quality control; on-stream radioisotope sensors and on-line computer for centralized process control; control of tailings, plant waste, or discharge; actual operating experience, including the acquisition, installation, and commissioning of instrument systems; instrumentation cost–benefit analysis with reference to plant throughput.

(*b*) Melting, refining, casting, and alloying operations:
Review of melt-shop or other reduction processes and related operations; progress in laboratory analysis and quality control; on-line use of isotope and related techniques; control of plant waste and discharge; actual operating experience; control system cost–benefit analysis.

(*c*) Manufacture of finished basic metal products:
Review of modern products, including laminated materials and honeycomb structures and manufacturing processes, with special reference to production-line speed and operating environments; progress in laboratory analysis and quality control; on-line control of mass per unit area and of coating operations; radiation curing of coating materials; actual operating experience with on-line systems; cost–benefit analysis.

(*d*) Research and development:
New applications of isotopes in research in metallurgy and other branches of science as related to metal industries; promising ideas not yet developed into working tools; future trends of development.

For further information, write the Administrative Secretary of the symposium, Miss G. Seiler, Division of External Relations, International Atomic Energy Agency, Karntner Ring 11, P. O. Box 590, A-1011 Vienna, Austria.

PHYSICAL ASPECTS OF NUCLEAR MEDICINE

A special summer program at M.I.T. from July 24 through July 28, 1972, will deal with the state of the art in physical problems related to nuclear medicine. Special emphasis will be placed on instrumentation, radiopharmaceuticals, dosimetry, and data processing as well as specific organ studies and therapy. The material should be of value to both physicians and physical scientists working in this area. The program is

jointly sponsored by the Harvard Medical School and M.I.T. through the Harvard–M.I.T. Program in Health Sciences and Technology. Some tuition grants will be available.

For further information, write to

Director of the Summer Session
Room E19-356
Massachusetts Institute of Technology
Cambridge, Mass. 02139

IAEA TO SPONSOR SEATTLE MEETING ON BEHAVIOR OF RADIONUCLIDES IN MARINE ENVIRONMENT

Seattle, Wash., will be the site of the July 10–14, 1972, Symposium on the Interaction of Radioactive Contaminants with the Constituents of the Marine Environment. Sponsored by the International Atomic Energy Agency, the meeting will cover the following topics:

A. Physical and chemical forms of radioactive contaminants and their stable natural isotopes in marine waters, particulate matter, and sedimentary particles:
   (i) Chemical reactions which take place after the introduction of fallout and radioactive waste into the sea, especially those which involve a change in chemical species.
   (ii) Chemical reactions which take place with radioactive contaminants and trace metals in rivers during their transport to the sea. These reactions concern (*a*) the change of dissolved chemical species, (*b*) the dissolution from and sorption by suspended matter, and (*c*) the reactions with dissolved and particulate organic matter.
   (iii) The sea bottom as a reservoir and sink for radionuclides and trace metals and the transport of these isotopes in conjunction with sediment transport.

B. The interaction of radionuclides with marine biota:
   (i) Biological interaction of radionuclides as a function of their physicochemical state in seawater.
   (ii) Flux of radionuclides through marine biota as a function of different environmental parameters. Dynamics of accumulation and loss, use of models and concepts such as biological half-lives for evaluating results, and reliability of extrapolation of laboratory results to the field.
   (iii) The transfer of radionuclides along marine food chains.
   (iv) The effects of ionizing radiation on marine biota.

C. Health and Safety. The effects of radionuclide contaminants in ocean water, biota, and sediment with respect to the evaluation of the hazards to man:
   (i) The application of both the critical pathway and specific activity approach for the evaluation of the dose to man.

D. The application of radiologically labelled environments:
   (i) Waste management control.
   (ii) The study of biogeochemical processes.
   (iii) The study of nonradioactive pollution.

For further information, write Miss C. H. de Mol van Otterloo, Division of External Relations, IAEA, Kärntner Ring 11, P. O. Box 590, A-1011 Vienna, Austria.

Abstracts of Recent Literature

Applications of Radioisotopes. Nuclear Engineering—Part XXII, L. H. Meyer (Ed.), Chemical Engineering Progress Symposium Series, Vol. 66, No. 106, 1970, published by the American Institute of Chemical Engineers, New York (13 papers, 105 pp.).

Supplementary Keywords: *radiation source; source preparation; energy source; production, radioisotope; industry; medicine; isotope use;* ^{60}Co; ^{244}Cm; ^{252}Cf.

The increasing variety in the applications of radioisotopes is highlighted by the papers given at the symposium on the Applications of Radioisotopes, sponsored by the Nuclear Engineering Division of the American Institute of Chemical Engineers, in Chicago, Nov. 30–Dec. 1, 1970. This volume includes the papers which discuss the preparation and properties of alpha, beta, gamma, and neutron sources and their uses in space, medicine, and industry. Radioisotopes have special and almost unique properties that suit them for applications in engineering. The good beginning—and tremendous potential—in the exploitation of radionuclides in this field is indicated by this volume.

The papers include general discussions of the uses of radioisotopes in process engineering, to solve mass-transfer problems; industry and aerospace, for numerous measurements; mining and industry, as sources in portable X-ray analyzers; medicine, as artificial heart devices; and industry, for on-stream process analysis by neutron activation. Certain radionuclides are discussed in some detail—^{60}Co as a heat and power source and for sterilizing disposable medical

products, ^{244}Cm in the form of Cm_2O_3 as a heat source, and ^{252}Cf as a neutron source. The work described indicates the intensifying effort to take full advantage of radioisotopes, which continue to become more abundant throughout the world as both products and by-products of the nuclear industry. (HPR)

Sterility Principle for Insect Control or Eradication, Proceedings of a symposium, Athens, Greece, Sept. 14–18, 1970, jointly organized by the IAEA and FAO, IAEA, Vienna, 1971 (STI/PUB/265) (542 pp., 49 papers, $14.00).

Supplementary Keywords: *source, beta; source, gamma; ecology; entomology; animal tracking; bibliography; conjoint use; data handling;* ^{22}Na; ^{32}P; ^{51}Cr; ^{57}Co; ^{59}Fe; ^{60}Co; ^{65}Zn; ^{89}Sr; ^{137}Cs.

Interest in nonpesticide methods of insect control is mounting. Increasing world population requires increasing food production, which in turn demands increase in pest control without insult to the environment. About one-third of the world's potential food is destroyed, in the field or in storage, by insects and other pests. For insect control, sterile-insect release is an advantageous alternative to pesticides.

This publication includes the 49 papers presented at the first symposium devoted entirely to the sterility principle for insect control or eradication (the fourth symposium on radiation and radioisotope applications in entomology); 92 participants from 40 countries and 6 international organizations attended. The papers were presented in the sessions:

Studies in Radiation Sterilization of Insects
Sterility Principle for Control of Fruit Flies
Sterility Principle for Control of Insects Affecting Man and Animals
Chemosterilization and Reproductive Physiology
Basic Biology and Artificial Rearing of Insects
Sterility Principle and Insects Attacking Food and Fibre Crops
Genetic Mechanisms of Insect Control
Insect Radiobiology

The presentations reflect the advances made during the last 10 years in the number of insect species studied, insect mass-rearing technology, use of ionizing radiation and chemicals to induce sterility, and extent of field trials. They also show the great promise of the sterility technique for insect control and the need for much additional work to ensure its large-scale routine use.

Methods alternative to pesticides must be developed without delay to control our major competitors for food. A store of needed information is contained in these symposium papers. (HPR)

Tests on Transport Packaging for Radioactive Materials, Proceedings of a seminar on Test Requirements for Packaging for the Transport of Radioactive Materials, Feb. 8–11, 1971, Vienna; IAEA, Vienna, 1971 (STI/PUB/285) (650 pp., 41 papers, $18.00).

Supplementary Keywords: *safety; safety container; radiation incident; regulation; data handling; bibliography.*

Packages of radioactive materials must contain and shield the materials under both normal and accident conditions. Usually, they are shipped with other goods and are handled by untrained workers. Standards for package design and tests to ensure adherence to the standards are rightly included in all transport regulations.

This was the first IAEA-sponsored seminar on this subject; 92 participants from 25 countries and 5 international organizations attended, and authors from 11 countries gave 41 papers. In nine sessions, the following subjects were discussed: transport conditions and accident experience, package testing, tests for particular design and construction features, calculative methods of predicting test results, and scale-model testing. In addition, two panel discussions were convened to review critically package testing and calculative methods plus scale-model testing.

These Proceedings give the papers presented and a record of discussions, of panelists' statements, and of questions and answers from participants. (HPR)

Study of Beta Backscattering for Measuring Coating Thickness (in Polish), by Ryszard Szepke, Instytut Badan Jadrowych, Warsaw, Report 1272/XV/I, 1971 (Polish Government Commission for Use of Nuclear Energy at the Palace of Culture and Science, Warsaw).

Published work (108 references) on beta-backscatter thickness measurements is reviewed, along with a computer program for use with coating–base combinations of various materials and thicknesses.

Design and Application of X-Ray Emission Analyzers Using Radioisotope X-Ray or Gamma-Ray Sources, by J. R. Rhodes (Columbia Scientific Industries), pp. 243-285, in *Energy Dispersion X-Ray Analysis: X-Ray and Electron Probe Analysis,* ASTM Special Technical Publication 485, American Society for Testing and Materials, Philadelphia, Pa., 1971.

This article, prepared under an AEC Division of Isotopes Development contract, reviews the present state of development and application of X-ray emission spectrometry using radioisotope-induced X- and

gamma-ray sources for excitation, with energy discrimination and dispersion techniques for spectrum analysis. A major portion of the paper is devoted to a review of published applications and covers determination of elements from aluminum to uranium and measurement of coating thickness. References are made to available portable, industrial, and laboratory instruments. 137 references. A few copies are available free from the Isotopes Information Center. (MG)

Nuclear Well Logging in Hydrology, Prepared by The Working Group on Nuclear Techniques in Hydrology of the International Hydrological Decade, IAEA, Vienna, 1971 (STI/DOC/10/126) (88 p., $3.00).

Supplementary Keywords: *source, gamma; source, neutron; geology; measurement, moisture; theory, applied; instrument; textbook; bibliography.*

In nuclear logging for hydrology, two main deficiencies are the general lack of coordinated information and the scarcity of hydrologists trained to do borehole logging and log analysis. These needs were recognized by the Working Group on Nuclear Techniques in Hydrology of the International Hydrological Decade (IHD). That group together with the IAEA Secretariat for the group—altogether 19 experts from 11 countries—prepared this report to meet the first need and to summarize the status of nuclear logging in hydrology. The information contained in it shows that nuclear logging is both qualitatively and quantitatively useful in hydrology. From nuclear logs, information can be gained about the physical, chemical, petrographic, and hydraulic properties of formations and their contained fluids.

The report is comprehensive but concise. An introductory section describes the purpose and limitations of nuclear well logging in hydrology, fundamentals of nuclear processes, hole construction and emplacement, and the instrumentation required. In a second section, four logging methods—natural-gamma, gamma–gamma, neutron, and tracer—are discussed in detail; for each method information (summarized in a very useful table) is given on principles, limitations, equipment, and applications. The third section, which is on applications and the interpretation of results, considers the characteristics of consolidated and unconsolidated strata and the characteristics and movement of fluids; the influence of well construction and drilling is discussed briefly. The final section—conclusions and recommendations—enumerates the advantages and disadvantages of nuclear logging in hydrology and suggests how maximum benefit can be gained from the technique during all the phases (exploration, evaluation, exploitation, and management) of groundwater development. A coordinated program that applies nuclear and other logging to each phase of water-resource development is shown to be useful and economical of time and money to the hydrologist. Practical information on nuclear-logging units and personnel requirements is appended.

With the need for coordinated information so aptly met, the remaining need—hydrologists trained in nuclear logging—should soon also be met. (HPR)

Bibliography on Isotope Separation by Ion Exchange, by D. E. J. Garman, P. M. Beach, J. J. Fardy, E. A. Newland, and P. K. Williamson, Australian Report AAEC-Bib-273, November 1970, ~200 references.

Radiation Processing of Poplar Wood (in Portuguese), by F. F. Alves, M. R. Barbosa, and M. N. Mariano, Portuguese Report LFEN-NI.57α, 1970.

Preliminary studies on irradiation of poplar wood impregnated with a mixture of monomers (styrene–acrylonitrile) indicated considerable improvement in physical properties (surface hardness, compression resistance, and water absorption) of the wood with a 50% polymer content. Both gamma (mixed fission product) and X (Van de Graaff) sources were used to give radiation doses of 1.1 to 1.5 Mrads.

Improving Plant Protein by Nuclear Techniques, Proceedings of a symposium, Vienna, June 8–12, 1970, IAEA, Vienna (STI/PUB/258).

Not only do the diets of many persons throughout the world lack calories, but they also contain inadequate protein, which is needed for normal maintenance of body tissues, growth of children, and lactation of mothers. More than 100 experts in food problems, from 30 countries and 6 international organizations, reviewed past experience and proposed new ways by which nuclear—and other advanced—techniques might be applied to the protein problem, in particular for the increased production of high-quality protein from plant sources. Plant sources generally have low protein content and are deficient in certain essential amino acids and thus do not meet nutritional needs, and increasing the quantity and nutritional quality of this protein is potentially the most feasible means of combating protein malnutrition.

Because of its discussions of radiation-induced mutations that change the protein content of seeds, this book falls within the interests of radioisotope

producers and users, although emphasis is on results rather than techniques. The use of isotopes in determining proteins is not covered, probably because the technique is too new, and isotopic tracer studies considered are routine ones. Nevertheless, the book provides important background for persons working in the field of nutrition. (MG)

Application of Induced Sterility for Control of Lepidopterous Populations, Proceedings of a panel, June 1–5, 1970, Vienna; organized by the Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture; IAEA, Vienna, 1971 (STI/PUB/281) (169 pp., 18 papers, $5.00).

Supplementary Keywords: *source, gamma; ecology; entomology; insect control; animal tracking;* ^{32}P; ^{60}Co.

Some of the worst pest insects belong to the order *Lepidoptera.* They are a constant threat to any increase in world agricultural production. The sterile-insect release method is a potential means—more desirable and less costly than pesticides—to their control. Sterilization can be effected by gamma irradiation, ^{60}Co being a favorite gamma source.

The concerted effort to control *Lepidoptera* population is evident from this publication, which summarizes a panel meeting of 30 experts from 12 countries. Of the 18 papers it contains, 12 describe work done with radionuclides—either as sources of gamma radiation or as insect tracers. The articles deal chiefly with recent advances in laboratory and field trials. General and specific recommendations of the panel are appended. The latter include the recommendation to study actively the possibility of releasing partially sterile moths to achieve population suppression. The probabilities of physiological and somatic damage and of decrease in competitiveness are associated with total sterility, whereas partial sterility gives less loss of competitiveness and takes advantage of the phenomenon of inherited sterility in progeny. The panel believes that the release of partially sterile moths could be an economical way to keep a natural population at a level below which the species becomes an economic pest. To guide investigators, they have divided the lepidopterous species into three groups according to the amount of information available on their radiation-induced sterility: those ready for field trials, those requiring further study, and those of economic importance for which data are needed.

The recommendations from another meeting are also appended—the panel and research coordination meeting on Ecology and Behavior of the *Heliothis* Complex as Related to the Sterile-Male Technique, Bogota, Colombia, May 18–21, 1970.

This publication should guide researchers in applying sterility control to lepidopterous pests and stimulate additional research needed to tip the scales in man's favor in his struggle with insects. (HPR)

Applications of Ionizing Radiations in Plastics and Polymer Technology, by Arthur F. Readdy, Jr., Report AD-725,940, Plastics Technology Evaluation Center, Picatinny Arsenal, Dover, N. J., available from NTIS (250 pp., $12.00).

This report covers both electron-beam and gamma-radiation (^{60}Co) processing. A possible market value of $\$1 \times 10^9$ for radiation-processed materials in the United States is predicted, which represents a considerable rise over the figures of $\$400 \times 10^6$ and $\$70 \times 10^6$ for 1970 and 1964, respectively.

Applications of Neutron Activation Analysis in Scientific Crime Investigation, Final Report, by H. R. Lukens and H. L. Schlesinger, Gulf General Atomic Report GA-10276, Sept. 2, 1970.

Final data on analysis of paper, gunshot residues, bullet-hole edges, and paint by neutron activation are reported. Earlier reports on these subjects are summarized in *Isotopes and Radiation Technology,* **9**(1): 39-40 (Fall 1971) and Sec. I, this issue.

Precipitation Scavenging (1970), Proceedings of a symposium, Richland, Wash., June 2–4, 1970, sponsored by Pacific Northwest Laboratory, Battelle Memorial Institute, and U. S. Atomic Energy Commission, R. J. Engelmann and W. G. N. Slinn (Coordinators), USAEC Technical Information Center, Oak Ridge, Tenn., 499 pp. (CONF-700601).

Supplementary Keywords: *activation, neutron; activable tracer; hydrology; meteorology; oceanology; material tracing; residence time; spectrometry; ion exchange; apparatus; pollution; atmosphere; sea;* ^{3}H; ^{7}Be; ^{22}Na; ^{24}Na; ^{37}Ar; ^{38}Cl; ^{39}Cl; ^{90}Sr; ^{131}I; ^{214}Bi; ^{214}Pb.

For cleansing the atmosphere, precipitation is a principal mechanism. Because of the importance of this process in the quality of our environment, a scientific meeting was devoted to scavenging by precipitation. The papers presented at that meeting constitute *Precipitation Scavenging (1970).* They assess the state of the art of precipitation-scavenging research and suggest a shift from the question "*How much* material is removed from the atmosphere by precipitation?" to

the more fundamental problem "*How* is the material scavenged?"

The significant role of isotopes—as both naturally occurring and added activable tracers and as both cosmogenic and fallout radionuclides—in answering the question is evident from the papers: (HPR)

Title	Authors	Isotopes
Stable Elements of the Atmosphere as Tracers of Precipitation Scavenging	L. A. Rancitelli, R. W. Perkins, T. M. Tanner, and C. W. Thomas	Ag, As, Au, Br, Cl, Co, Cr, Cs, Cu, Fe, Hg, K, Mn, Na, Rb, Sb, Sc, Se, Zn
Scavenging of Tracer in Severe Storms	A. N. Dingle	In
Use of Natural Radioactivities to Estimate Large-Scale Precipitation Scavenging	L. Machta, R. J. List, M. E. Smith, Jr., and H. Oeschger	^{7}Be, ^{37}Ar
Mechanism of Iodine Injection from the Sea Surface	C. S. Martens and R. C. Harriss	^{22}Na, ^{131}I
In-Cloud Scavenging Analysis from Cosmogenic Radionuclide Measurements	R. W. Perkins, C. W. Thomas, J. A. Young, and B. C. Scott	^{24}Na, ^{38}Cl, ^{39}Cl, ^{214}Bi, ^{214}Pb
Tropospheric Scavenging of ^{90}Sr and ^{3}H	P. W. Krey and B. Krajewski	^{3}H, ^{90}Sr

Gamma-Ray Energy. Tables for Neutron Activation Analysis (second edition), R. H. Filby, A. I. Davis, K. R. Shah, G. G. Wainscott, W. A. Haller, and W. A. Cassatt (Comps. and Eds.), Washington State University Nuclear Radiation Center, Pullman, 1970 [Report WSUNRC-97(2)].

The October 1969 edition of the "Tables" was based on the literature through 1966. Since 1966, many nuclide decay schemes and energy levels have been studied using high-resolution Ge(Li) spectrometry, resulting in more precise energy and intensity data. The data used in the first edition had been stored in an IBM 360/67 data cell to allow continual updating, which was done as of December 1969 for this second edition. The main format is the same as that of the first edition, but some changes have been made to conform with current usage, and some additional data have been included.

Preliminary Study on the Characteristics and Design Parameters for a Mössbauer Resonant Detector, by J. J. Spijkerman, J. C. Travis, P. A. Pella, and J. R. DeVoe, National Bureau of Standards, NBS Technical Note 541, January 1971.

Progress in the design and fabrication of a resonant detector for Mössbauer spectroscopy is described. This report reviews all the methods of detection for Mössbauer spectroscopy and the expected advantages of the resonant detector. The use of conversion-electron detection considerably enhances the signal-to-noise ratio, with a decrease in line width. Efforts to produce an iron-bearing resonant material are described.

Diagnostic Nuclear Medicine, by E. R. Powsner and D. E. Raeside, Grune & Stratton, Inc., New York, 1971 (657 + xx pp., $30.00).

This book contains the material presented in the Northwestern University Medical School course in diagnostic applications of radioisotopes and is intended for use not only by resident and practicing physicians but also by technicians. The chemical and physical bases of radioisotopic diagnostic procedures and of therapy with radioactive pharmaceuticals are discussed along with the instrumentation needed for and the biological effects of ionizing radiation. Various diagnostic procedures are described, first in narrative form with explanations and references to original work, and then in laboratory manual style. Mathematical calculations used in diagnosis are illustrated.

The book is well written and well documented (approximately 1400 references) and should be very useful to both physicians and technicians. (MG)

Review of *The Uses of Cyclotrons in Chemistry, Metallurgy, and Biology*, Proceedings of a conference, St. Catherine's College, Oxford, England, Sept. 22–23, 1969; C. B. Amphlett (Ed.); Butterworth and Company, Ltd., London, 1970. (Available from Daniel Davey and Company Inc., Hartford, Conn.) (400 pp., 34 articles, $6.60).

Supplementary Keywords: *activation, charged particle; accelerator; chemistry, analytical; production, accelerator; target preparation, stable; physics; medicine; industry, pharmaceutical; radiolysis; dosimetry; radioactive decay; instrument; recoil; cross section and yield; technique; spectrometry; effect of radiation on material; bibliography; fission products; actinide.*

The availability of variable-energy and compact cyclotrons, purchasable to order, has resulted in an ever-

increasing use of cyclotrons for research in disciplines other than nuclear physics. This increasing scope of application more than justified the decision of the United Kingdom Atomic Energy Authority (UKAEA) to organize a meeting devoted entirely to the uses of cyclotrons. The meeting logically followed the Fifth International Cyclotron Conference. The attendance of 163 participants from 19 countries provided a unique opportunity for exchange of information and ideas among designers, operators, and users.

Widely diverse topics were discussed in 34 papers presented at 8 sessions, as follows:

Session	Topic	No. of Papers
1	Nuclear Chemistry	5
2	Radiation Chemistry	4
3	Isotope Production	6
4	Radiation Biology and Medicine	4
5	Techniques and Instrumentation	5
6	Radiation Damage	3
7	Activation Analysis	4
8	Excitation Functions	2
–	(Round Table and Discussion)	1

The proceedings contain abstracts of the papers, as well as the many valuable illustrations and references. In the first session, the topics discussed included nuclear charge dispersion in the fission of heavy nuclei, decay of ^{68}Gd, search for new isotopes and superheavy elements and the tentative identification of ^{241}Cf, and the chemical behavior of Mo recoil atoms. Cyclohexane, Fricke dosimeter solution, bacterial cells, oxide powders, and supercritical water were among the materials considered in session 2. The production of isotopes for medical and pharmaceutical uses and the practical problems associated with isotope production received emphasis in session 3. The properties of cyclotron beams and the use of the cyclotron to irradiate biological specimens and phages and for radiation therapy were considered in session 4. Useful information about techniques of on-line fission experiments and nuclear spectroscopy, irradiation of extended objects, fast-neutron-flux measurement, and target-system production was given in session 5. Reactor materials and metallurgical specimens were of chief importance in the session 6 discussions. In session 7, the influence of energy distribution in charged-particle activation analysis and the determinations of a number of elements by charged-particle activation were described. A novel method for measuring excitation functions for charged-particle reactions on gases and the evaluation of unknown excitation functions for (α,xn) and (d,xn) reactions were given in session 8. The conference concluded with a discussion of terms used in the production of radioisotopes by charged-particle bombardment.

The conference answered a need for interaction among all workers in the field—a need that is almost mandatory in work which is so important and costly. This record of the proceedings is certain to be of broad interest and use. (HPR)

Nuclear Techniques for Mineral Exploration and Exploitation, Proceedings of a panel, Cracow, Poland, Dec. 8–12, 1969, organized by the International Atomic Energy Agency; IAEA, Vienna, 1971 (STI/PUB/279) (187 pp., 15 papers, $5.00).

Supplementary Keywords: *activation, neutron; source, X ray; geology; geophysics; industry, mining; logging; mobile; X-ray fluorescence; spectrometry; plant scale; conjoint use; backscatter; semiconductor; data handling; comparison; bibliography; Au; Rn; U.*

In December 1969, the International Atomic Energy Agency convened a panel to review the status of the use of nuclear techniques in exploring for and exploiting mineral resources. The particular interest was to identify those techniques most suitable for adoption by developing countries. Nineteen panel members from 10 countries, both advanced and developing, participated. This publication contains the 15 papers presented by the panel members and also a summary of the panel's findings.

Broad discussions of the application of nuclear techniques for developing mineral resources—from field experience to on-stream analysis—are given in five papers. Six papers describe the use of activation analysis, and four are concerned with X-ray-fluorescence analysis. One article reviews the advantages of computer techniques in activation analysis; another describes how measurement of radon in soil is used to explore for uranium. Determination of a single element—gold—is the subject of three papers.

The panel agreed to use certain specified terminology in an effort to standardize the discussions. To summarize the meeting, which related primarily to metalliferous minerals and bulk deposits (coal, bauxite, and phosphate), conclusions were given regarding the use of nuclear techniques in the reconnaissance, assessment, and evaluation of minerals; in mine operations and control; and in mineral processing and control. (HPR)

Publications by Isotopes Information Center

Oak Ridge National Laboratory
Post Office Box X
Oak Ridge, Tenn. 37830

ORNL-IIC-1, Publications on Isotopes at Oak Ridge National Laboratory, 1946–1963, Robert H. Lafferty, Jr., P. S. Baker, and Martha Gerrard, July 1964.

ORNL-IIC-2, Production of Calcium-47, with Literature Review of Uses, P. S. Baker, Martha Gerrard, and Robert H. Lafferty, Jr., May 1964.

ORNL-IIC-3, Iodine-125, P. S. Baker and Martha Gerrard, February 1972.

ORNL-IIC-4, Iodine-132: Review of Properties, Uses, and Methods of Preparation, Martha Gerrard, John J. Pinajian, and P. S. Baker, November 1968.

ORNL-IIC-5, Proceedings of Symposium on Low-Energy X- and Gamma Sources and Applications, held at Illinois Institute of Technology Research Institute, Chicago, Ill., Oct. 20–21, 1964, Philip S. Baker and Martha Gerrard (Eds.), November 1965.

ORNL-IIC-6, List of AEC Radioisotope Customers with Summary of Radioisotope Shipments, FY 1965, P. S. Baker (Comp.), March 1966.

ORNL-IIC-7, Proceedings of Information Meeting on Irradiated Wood–Plastic Materials, held at Conrad Hilton Hotel, Chicago, Ill., Sept. 15, 1965, R. E. Greene and P. S. Baker (Eds.), March 1966.

ORNL-IIC-8, Reactor Yield Calculations for 81 Radioisotopes Produced by (n,γ) Reactions at Fluxes of 10^7 to 10^{16} n/cm^2•sec for Irradiated Times of 30 Minutes to One Year, T. C. Whitson and C. W. Friend, April 1966.

ORNL-IIC-9, List of AEC Radioisotope Customers with Summary of Radioisotope Shipments, FY 1966, P. S. Baker (Comp.), September 1967.

ORNL-IIC-10, Proceedings of Second Symposium on Low-Energy X- and Gamma Sources and Applications, held at University of Texas, Austin, Mar. 27–29, 1967, Philip S. Baker and Martha Gerrard (Eds.), September 1967.

ORNL-IIC-11, Radiation Pasteurization of Fruits and Vegetables—A Bibliography, A. S. Abdel-Kader and E. C. Maxie (P. S. Baker, Ed.), September 1967.

ORNL-IIC-11(Suppl. 1), Radiation Pasteurization of Fruits and Vegetables—A Bibliography, F. E. McKinney, August 1968.

ORNL-IIC-11(Suppl. 2), Radiation Pasteurization of Fruits and Vegetables—A Bibliography, F. J. Weiss (F. E. McKinney, Ed.), April 1969.

ORNL-IIC-11(Rev.), Radiation Pasteurization of Fruits and Vegetables. A Bibliography, F. E. McKinney, January 1972.

ORNL-IIC-12, Special Sources of Information on Isotopes, F. E. McKinney, R. H Lafferty, Jr., and P. S. Baker, January 1968.

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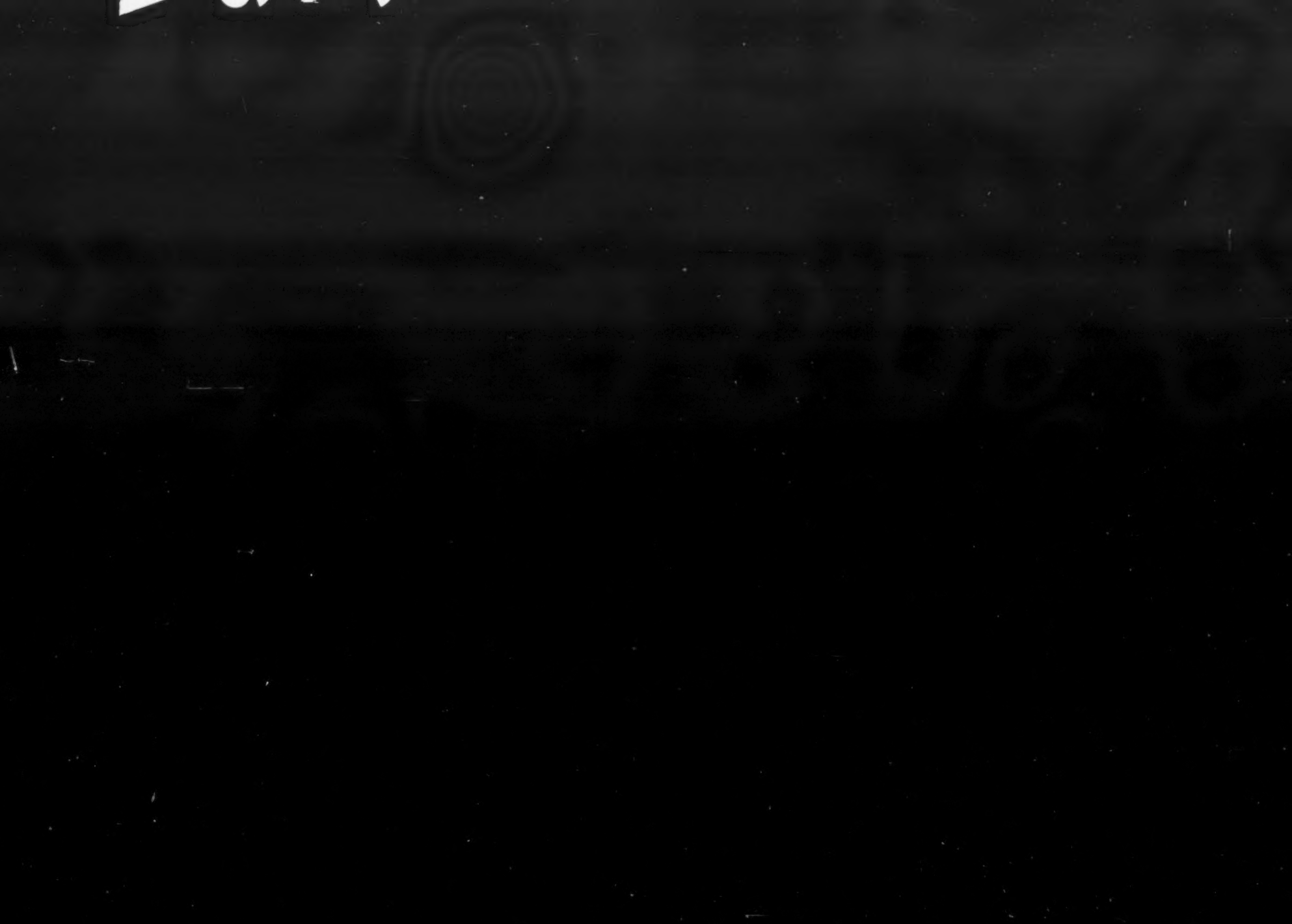
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